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Radiocarbon chronology and environment of woolly mammoth (*Mammuthus primigenius* Blum.) in northern Asia: results and perspectives

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Abstract

This paper reviews the history of the woolly mammoth (*Mammuthus primigenius* Blum.) in Siberia and adjacent northern Asia. The particular emphases are the chronology and environment of mammoth existence and extinction, based on about 530 radiocarbon dates from about 230 localities with mammoth remains and palaeoenvironmental records of the last 50,000 years. Until ca. 12,000 radiocarbon years ago (BP), mammoths inhabited all of northern Asia, from the High Arctic to southern Siberia and northeastern China. Since ca. 12,000 BP, mammoth disappeared from major parts of Siberia and adjacent northern Asia, and survived mainly in the Arctic regions of Siberia, north of 69° northern latitude. However, recently, it was found that some mammoth populations continued to exist in central and southern Western Siberia until ca. 11,100–10,200 BP. 'Normal' size mammoths became extinct in mainland Siberia at the Pleistocene–Holocene boundary, ca. 9700 BP. On Wrangel Island in the High Arctic, small-sized mammoths survived into the Middle–Late Holocene, ca. 7700–3700 BP. Compared with previous studies, it is now possible to reveal the complex nature of the process of final mammoth extinction in Siberia, with some small populations surviving outside of the Arctic until ca. 10,000 BP.

The extinction of mammoth was most probably caused by a combination of factors, such as global warming in the Late Glacial (since ca. 15,000 BP) and the disintegration of landscapes suitable for mammoths throughout the Upper Pleistocene, such as light forests with vast open spaces occupied by meadows and forest tundra. The expansion of forest vegetation after the Last Glacial Maximum in Siberia, including its northeastern part, created unsuitable habitats for herbivorous megafauna, especially for mammoths. However, the Holocene environment of Wrangel Island was not of 'glacial' type and this requires further studies.

The relationship between mammoths and Upper Palaeolithic humans is also considered. The role of humans in the process of mammoth extinction was of secondary importance. The lack of direct evidences of mammoth hunting limits the estimation of its role in Upper Palaeolithic human subsistence.

Siberia is undoubtedly the area where the final extinction of mammoth occurred, and the future study of this process is important to understand the patterns of Pleistocene megafaunal extinction in the Northern Hemisphere.

Keywords: Woolly mammoth; Radiocarbon dating; Palaeoenvironment; Upper Pleistocene; Late Glacial; Holocene; Palaeolithic; Siberia; Northern Asia

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1. Introduction

The woolly mammoth [*Mammuthus primigenius* (Blumenbach, 1799)] (hereafter mammoth) is the most important representative of the Eurasian Upper Pleistocene megafaunal complex, along with woolly rhinoceros, cave lion and bear, auroch, bison, giant deer, cave hyena, and other animals. The study of mammoth extinction patterns is crucial for understanding the impact of global environmental changes on the mammalian populations at the end of the Pleistocene, ca. 10,000 radiocarbon years ago (BP). Northern Asia, which comprises Siberia (a territory of ca. 12,000,000 km^2) and the adjacent Russian Far East, Kazakhstan, northeastern China, Mongolia, and Japan, is the most important region for the investigation of mammoth existence and extinction, particularly with the help of the radiocarbon (^{14}C) dating method. Scientific studies of mammoth in Siberia have been conducted for more than 100 years, since the pioneering work accomplished by Chersky (1891). Based on the most recent data, it is clear that the mammoth lived in northern Asia since at least the latter part of the Middle Pleistocene, ca. 300,000 years ago (Krasnov, 1984, pp. 245–467) and perhaps even earlier, since the end of the Lower Pleistocene, ca. 800,000 years ago (Lister and Sher, 2001). For events in the geological history of the Earth during the last 40,000–50,000 years, ^{14}C dating is widely used as the main method of chronological studies (cf. Martin and Klein, 1984). The latest mammoths have been ^{14}C-dated to ca. 9700 BP in mainland Siberia and to ca. 3700 BP on Wrangel Island (Stuart et al., 2002).

The objective of this review is to present the updated information on the ^{14}C chronology and environment of mammoths in northern Asia, using the latest compilations as well as some unpublished data of the authors. As a result of the ^{14}C Database analysis, palaeogeographical and palaeoecological interpretations will be made. The possible role of Palaeolithic humans in the process of mammoth extinction will also be discussed.

2. Materials and methods

The first ^{14}C dates, obtained from mammoth remains in Siberia, were published in the early–mid 1960s (Heintz and Garutt, 1964, 1965; Heintz, 1966). In the 1970s–1990s, numerous ^{14}C dates were produced on mammoth bones and tusks, and soft tissues preserved in the permafrost. The first summary of the mammoth ^{14}C dates from the Soviet Union territory corresponds in general to the northern Asia, published in the late 1970s by Orlova (1979), includes 23 ^{14}C values for Siberia. Subsequently, Stuart (1991) listed 55 ^{14}C dates from Siberia. Publication of the mammoth ^{14}C dates intensified in the 1990s and early 2000s (Vartanyan et al., 1995; Sulerzhitsky, 1995, 1997; Sulerzhitsky and Romanenko, 1997, 1999; Vasil'chuk et al., 1997, 2000; Schirrrmeister et al., 2002; MacPhee et al., 2002). Recently, comprehensive summaries of the mammoth ^{14}C dates from Siberia and adjacent northern Asia were published (Orlova et al., 2000a,b, 2002; Kuzmin et al., 2000, 2001a,b, 2003). In early 2003, we have in total about 530 published ^{14}C values, obtained *directly from mammoth remains* in northern Asia, and most of them are catalogued in the form of a Database with access via the Internet (http://www.uiggm.nsc.ru/geology/evol/lab924/orlova/index.htm).

The original ^{14}C data presented here are organized by localities (Table 1), with indications of multiple dates obtained from the same sample or from the same individual carcass. The position of localities is indicated by latitude and longitude, given as decimal values (e.g. 70.50 N means 70°30′ northern latitude), and determined with consultation of the U.S. Defense Mapping Agency Operational Navigation Charts (scale of 1:1,000,000). The data sources are mostly original publications where ^{14}C values appeared for the first time, and/or summary papers. For Russian sources, the citation style follows the U.S. Library of Congress system, with Romanization of original titles and their translation in brackets, and with only Romanization of the source name.

Radiocarbon dating of the northern Asian mammoth remains was performed in 25 laboratories, including the Geological Institute, Russian Academy of Sciences, Moscow, Russia (Lab code GIN; 215 values or 45.0%); Institute of Geology, Siberian Branch of the Russian Academy of Sciences, Novosibirsk, Russia (SOAN; 85 values, 17.9%); St.-Petersburg State University, St.-Petersburg, Russia (LU; 49 values, 10.2%); Beta Analytic, Miami, FL, USA (Beta; 29 values, 6.1%); NSF-Arizona AMS Facility,

Table 1
Radiocarbon dates for the woolly mammoth remains in Siberia and adjacent northern Asia

No.	Site name, location, layer no.	Latitude, N	Longitude, E	^{14}C date, BP	Sigma (± σ)	Lab code and no.
1	Wrangel Island	71.00	179.00	3685	60	Ua-13366
2	Wrangel Island	71.00	179.00	3730	40	LU-2741
3	Wrangel Island	71.00	179.00	3920	30	GIN-6980
4	Wrangel Island	71.00	179.00	4010	50	LU-2798
5	Wrangel Island	71.00	179.00	4040	30	LU-2808
6	Wrangel Island	71.00	179.00	4370	70	GIN-8249
7	Wrangel Island	71.00	179.00	4400	40	LU-2756
8	Wrangel Island	71.00	179.00	4410	50	LU-2768
9	Wrangel Island	71.00	179.00	4740	40	LU-2556
10	Wrangel Island	71.00	179.00	4900	40	LU-2740
11	Wrangel Island	71.00	179.00	5110	40	LU-2794
12	Wrangel Island	71.00	179.00	5200	30	LU-2745
13	Wrangel Island	71.00	179.00	5250	40	LU-2744
14	Wrangel Island	71.00	179.00	5310	90	LU-2742
15	Wrangel Island	71.00	179.00	5480	50	LU-2535
16	Wrangel Island[1]	71.00	179.00	6260	50	LU-2799
17	Wrangel Island[1]	71.00	179.00	6360	60	AA-11529
18	Wrangel Island	71.00	179.00	6610	50	LU-2558
19	Wrangel Island[2]	71.00	179.00	6750	30	GIN-6990
20	Wrangel Island[2]	71.00	179.00	6760	50	LU-2736
21	Wrangel Island	71.00	179.00	6890	50	LU-2810
22	Wrangel Island	71.00	179.00	7040	60	LU-2746
23	Wrangel Island[3]	71.00	179.00	7250	60	LU-2809
24	Wrangel Island[3]	71.00	179.00	7295	95	AA-11530
25	Wrangel Island	71.00	179.00	7360	50	LU-2559
26	Wrangel Island	71.00	179.00	7710	40	GIN-6995
27	Nizhnaya Taymyra River	75.25	99.73	9670	60	GIN-1828
28	Pronchishchev Coast	76.75	110.50	9780	40	GIN-8256
29	Nizhnaya Taymyra River	75.25	99.73	9860	50	GIN-1495
30	Bikada River	74.92	106.58	9920	60	GrA-17350
31	Yuribey River (Gydan Pen.)	68.92	71.00	10,000	70	LU-1153
32	Nyengatiatari River	74.83	106.17	10,070	60	GIN-10508
33	Engelgardt Lake	75.10	110.30	10,100	100	GIN-1489
34	Kupchiktakh Lake	73.58	101.13	10,200	40	GIN-11138a
35	Lugovskoe	61.05	68.57	10,210	135	SOAN-4752
36	Goltsovaya River	76.80	104.58	10,270	40	Beta-148640
37	Nyunkarakutari River	75.35	105.50	10,270	120	GIN-10507
38	Nizhnaya Taymyra River	75.25	99.73	10,300	100	GIN-1828k
39	Mutnaya Seyakha River	70.15	69.00	10,350	50	GIN-6386
40	Berelekh	70.55	149.05	10,370	70	SOAN-327
41	Sabettayakha River	71.15	71.33	10,420	130	AA-27378
42	Yuribei River (Yamal Pen.)	68.92	69.70	10,460	120	AA-27377
43	Nganasanskaya River	74.40	99.41	10,680	70	GIN-3768
44	Krasnaya River	74.57	98.50	10,790	100	GIN-10552
45	Lugovskoe[4]	61.05	68.57	10,820	170	SOAN-4943
46	Sosva River	59.16	62.08	11,080	160	SOAN-4842
47	Volchya Griva	54.50	80.20	11,090	120	SOAN-4921
48	Taymyr Lake	74.05	93.10	11,140	180	GIN-3067
49	Lugovskoe	61.05	68.57	11,310	380	SOAN-4755
50	Mamont River	75.15	96.00	11,450	250	T-297
51	Oktyabrskoi Revolutsii Island	78.82	97.67	11,500	60	LU-610
52	Lugovskoe	61.05	68.57	11,840	95	SOAN-4753

(continued on next page)

Table 1 (*continued*)

No.	Site name, location, layer no.	Latitude, N	Longitude, E	^{14}C date, BP	Sigma (± σ)	Lab code and no.
53	Arylakh Lake	74.42	107.58	11,940	40	Beta-148663
54	Konzhul	55.33	92.47	11,980	155	SOAN-4953
55	Berelekh	70.55	149.05	12,000	130	LU-149
56	Wrangel Island	71.00	179.00	12,010	110	LU-2823
57	Malta	53.00	103.50	12,015	85	AA-20930
58	Bikada River	74.83	106.00	12,050	150	GIN-10506
59	Baskura Pen. (Taymyr Lake)	74.03	100.00	12,100	80	GIN-1783
60	Berelekh	70.55	149.05	12,240	160	LU-149
61	Severnaya River	75.50	112.00	12,260	120	GIN-2943r
62	Severnaya River	75.50	112.00	12,450	120	GIN-3242
63	Volchya Griva	54.50	80.20	12,520	150	SOAN-4290
64	Dyuktai Cave, layer 7a	59.25	132.67	12,520	250	IM-462
65	Achchagy-Allaikha River[5]	69.00	147.30	12,530	60	SOAN-2203
66	Shchuchya River	67.38	67.87	12,535	80	AA-27372
67	Achchagy-Allaikha River[5]	69.00	147.30	12,570	80	MAG-826
68	Batpak	50.50	72.75	12,570	400	KIGN-199
69	Urz	55.00	159.00	12,630	50	GIN-3420
70	Wrangel Island	71.00	179.00	12,750	50	GIN-6987
72	Bikada River	74.53	106.30	12,780	80	GIN-2677
72	Lugovskoe	61.05	68.57	12,830	350	SOAN-4754
73	Berelekh	70.55	149.05	12,850	110	LU-1055
74	Yugoyar Berezovsky	59.00	69.00	12,860	90	SOAN-1283
75	Konzhul	55.33	92.47	12,860	175	SOAN-4954
76	Xiaonanshan	46.78	134.03	12,900	410	PV-0179
77	Aion Island	69.78	168.00	12,950	130	GIN-8241
78	Lugovskoe	61.05	68.57	12,970	160	SOAN-5063
79	Wrangel Island	71.00	179.00	12,980	80	LU-2792
80	Irtysh River	58.05	69.50	13,140	100	SOAN-4803
81	Lugovskoe[4]	61.05	68.57	13,205	60	OxA-12031
82	Berelekh	70.55	149.05	13,205	150	LE-2335
83	Listvenka, layer 12G	55.92	92.33	13,260	160	SOAN-4868
84	Afontova Gora 2	56.10	92.50	13,260	250	GIN-7538
85	Bolshaya Balakhnya River	75.30	105.00	13,340	240	GIN-2758a
86	Afontova Gora 2, layer 2	56.10	92.50	13,310	140	GIN-7542
87	Bolshaya Balakhnya River	75.30	105.00	13,340	240	GIN-2758a
88	Afontova Gora 2, layer 3	56.10	92.50	13,350	60	GIN-7539
89	Kirpichnyi	61.03	68.63	13,430	105	SOAN-5064
90	Lugovskoe[6]	61.05	68.57	13,450	50	OxA-12029
91	Lugovskoe[7]	61.05	68.57	13,455	60	OxA-12030
92	Lugovskoe	61.05	68.57	13,465	50	KIA-19643
93	Lugovskoe[6]	61.05	68.57	13,490	155	SOAN-4942
94	Sopochnaya	72.83	106.75	13,560	40	Beta-148636
95	Volchya Griva	54.50	80.20	13,600	230	SOAN-111
96	Shokalsky Island[8]	73.00	74.40	13,600	160	AA-27376
97	Afontova Gora 2, layer 4	56.10	92.50	13,650	70	GIN-7540
98	Shokalsky Island[8]	73.00	74.40	13,650	170	GIN-8427
99	Berelekh	71.00	145.00	13,700	800	MAG-114
100	Kotelny Island	75.00	138.00	13,700	100	GIN-8230
101	Lugovskoe[7]	61.05	68.57	13,720	160	SOAN-4940
102	Khorol[9]	44.15	131.78	13,750	780	TIG-51
103	Afontova Gora 2, layer 2	56.10	92.50	13,930	80	GIN-7541
104	Yuribey River (Yamal Pen.)	68.88	70.75	13,940	170	AA-27379
105	Aion Island	69.78	168.00	14,000	120	GIN-8242
106	Aion Island	69.78	168.00	14,120	170	GIN-8241a

Table 1 (*continued*)

No.	Site name, location, layer no.	Latitude, N	Longitude, E	^{14}C date, BP	Sigma (± σ)	Lab code and no.
107	Volchya Griva	54.50	80.20	14,200	150	SOAN-78
108	Volchya Griva	54.50	80.20	14,280	285	SOAN-4292
109	Sobo-Sise Island[10]	72.47	128.42	14,340	50	GIN-4115
110	Uelen	66.30	170.00 W	14,380	70	GIN-7289
111	Zelenaya Seyakha River	70.15	69.00	14,400	80	GIN-7292
112	Nizhneirtyshskoe	58.07	68.19	14,510	195	SOAN-4956
113	Malta[11]	53.00	103.50	14,720	190	GIN-8476
114	Malta	53.00	103.50	14,750	120	GIN-97
115	Ulakhan-Yuryakh River	72.12	104.00	14,800	50	GIN-3518
116	Volchya Griva	54.50	80.20	14,800	150	SOAN-111A
117	Malta[11]	53.00	103.50	14,940	170	AA-27374
118	Shirokostan Peninsula	72.36	139.73	15,000	70	GIN-8255
119	Main River	65.00	171.00	15,100	70	GIN-5370
120	Gari 1	59.24	62.20	15,150	280	SOAN-4462
121	Khorol[9]	44.15	131.78	15,300	140	Ki-1130
122	Sabler Cape (Taymyr Lake)	74.53	100.50	15,390	50	Beta-148642
123	Wrangel Island	71.00	179.00	15,400	100	GIN-8258
124	Lugovskoe	61.05	68.57	15,420	215	SOAN-5065
125	Kotelny Island	75.30	140.00	15,420	100	LU-1671
126	Khaergas	62.42	133.00	16,000	300	IM-887
127	Nikolskaya Cave	55.48	59.48	16,130	310	SOAN-4804
128	Troitskaya	54.10	61.40	16,300	300	IERZH-165
129	Listvenka, layer 20	55.92	92.33	16,300	600	GIN-6093
130	Gari 1	59.24	62.34	16,320	450	SOAN-4461
131	Bolshaya Balakhnya River	75.30	105.00	16,330	100	GIN-3130
132	Gari 1	59.24	62.34	16,700	240	SOAN-4843
133	Evalga	59.38	62.33	17,050	160	SOAN-4844
134	Ushlep, layer 3	52.85	86.68	17,100	390	SOAN-5044
135	Listvenka, layer 19	55.92	92.33	17,200	230	SOAN-5084
136	Isha River	52.01	86.32	17,220	245	SOAN-3504
137	Kaverga River	57.23	112.25	17,290	100	GIN-8983
138	Khorol[9]	44.15	131.78	17,400	150	Ki-1301
139	Niryakan River	57.22	111.83	17,450	100	GIN-10908
140	Parisento River	70.11	75.46	17,500	300	GIN-7576
141	Isha River	52.01	86.32	17,600	500	SOAN-3503
142	Tesa River	57.30	112.00	17,610	200	SOAN-4418
143	Lower Lena River	70.00	125.00	17,780	80	GIN-5042
144	Volchya Griva	54.50	80.20	17,800	100	GIN-11463
145	Rychkovo	59.27	62.33	17,810	320	SOAN-4463
146	Shestakovo	55.64	88.00	18,040	175	SOAN-3610
147	Shikaevka 2	56.00	65.92	18,050	95	SOAN-2211
148	Bolshaya Balakhnya River	73.50	105.08	18,190	60	Beta-148646
149	Lugovskoe	61.05	68.57	18,250	1100	SOAN-3838
150	Faddeevsky Island	75.26	144.00	18,500	120	GIN-8229
151	Kochegur	55.85	88.05	18,580	240	SOAN-4945
152	Sosva River	63.12	62.38	18,600	230	SOAN-4845
153	Shlenka	55.20	92.05	18,600	2000	GIN-2862
154	Bur River	71.40	119.00	18,680	120	GIN-5046
155	Amudai River	73.00	119.00	18,700	100	GIN-6099
156	Tarachikha	55.15	91.10	18,930	320	LE-3834
157	Pyshma River	57.12	63.95	18,990	340	SOAN-4815
158	Shestakovo	55.64	88.00	19,190	310	SOAN-3609
159	Oktyabrskoi Revolutsii Island[12]	79.90	94.58	19,270	300	LU-654B

(continued on next page)

Table 1 (*continued*)

No.	Site name, location, layer no.	Latitude, N	Longitude, E	^{14}C date, BP	Sigma (±σ)	Lab code and no.
160	Middle Yenisey River	53.55	92.00	19,500	200	GIN-2859
161	Oktyabrskoi Revolutsii Island[12]	79.90	94.58	19,640	330	LU-654A
162	Middle Yenisey River	53.30	91.40	19,700	200	GIN-2861
163	Evalga	59.38	62.33	19,710	205	SOAN-4464
164	Malta	53.00	103.50	19,900	800	GIN-7705
165	Bolshaya Balakhnya River*	73.53	105.82	19,910	130	UtC-8137
166	Chulym River	55.05	90.00	19,960	80	GIN-3016
167	Oktyabrskoi Revolutsii Island	79.47	96.75	19,970	110	LU-688
168	Kotelny Island	75.30	140.00	19,990	110	LU-1970
169	Wrangel Island	71.00	179.00	20,000	110	LU-2807
170	Middle Yenisey River	53.55	92.00	20,100	300	GIN-3017
172	Shlenka	55.20	92.05	20,100	100	GIN-2863
172	Shirokostan Peninsula	72.36	139.73	20,100	150	GIN-8263
173	Mogochino	57.75	83.52	20,140	240	SOAN-1513
174	Chulym River	55.05	90.00	20,200	100	GIN-2860
175	Malta	53.00	103.50	20,340	320	OxA-6192
176	Bolshaya Balakhnya River*	73.53	105.82	20,380	140	UtC-8138
177	Bolshaya Balakhnya River*	73.53	105.82	20,390	160	UtC-8139
178	Niryakan River	57.22	111.83	20,400	100	GIN-9665
179	Dudypta River	72.08	96.25	20,400	100	GIN-3952
180	Malta	53.00	103.50	20,440	240	GIN-8475
181	Shestakovo	55.64	88.00	20,480	180	SOAN-3607
182	San Shan	45.50	126.33	20,580	600	ZK-425-0
183	Verkhnaya Taymyra River	74.15	99.39	20,600	90	GrA-17347
184	Verkhnaya Taymyra River	74.15	99.39	20,620	70	Beta-148647
185	Lyzhin Mys	59.50	62.25	20,630	220	SOAN-220
186	Malta	53.00	103.50	20,700	150	GIN-7709
187	Shestakovo	55.64	88.00	20,770	560	SOAN-3218
188	Taymyr Peninsula	74.00	103.00	20,800	70	Beta-148633
189	Malta	53.00	103.50	20,800	120	GIN-9508
190	Malta	53.00	103.50	20,800	140	GIN-7710
191	Malta	53.00	103.50	20,800	200	GIN-7669
192	Malta	53.00	103.50	20,900	200	GIN-7668
193	Faddeevsky Island	75.25	144.00	20,900	100	GIN-5760
194	Mudanjiang	44.63	129.58	20,910	1000	ZK-118-0
195	Baskura Peninsula	74.27	101.58	20,950	190	GrA-17604
196	Malta	53.00	103.50	21,000	110	GIN-9510
197	Malta	53.00	103.50	21,100	150	GIN-7703
198	Malta	53.00	103.50	21,100	140	GIN-7706
199	Lower Lena River	70.00	125.00	21,260	310	LU-786
200	Malta	53.00	103.50	21,300	300	GIN-7704
201	Malta	53.00	103.50	21,300	110	GIN-7702
202	Pakhtcha River	56.35	161.00	21,300	400	GIN-2224
203	Shestakovo	55.64	88.00	21,300	420	SOAN-3611
204	Malta	53.00	103.50	21,340	240	OxA-6193
205	Malta	53.00	103.50	21,400	110	GIN-9509
206	Khaergas	62.42	133.00	21,500	775	SOAN-4249
207	Onot River[13]	52.72	102.00	21,520	155	SOAN-4149
208	Malta	53.00	103.50	21,600	170	GIN-8475
209	Malta	53.00	103.50	21,600	200	GIN-7708
210	Tanon River	59.45	150.55	21,600	200	GIN-6309
211	Mamontovaya Khayata	71.28	129.42	21,630	240	LU-1328
212	Malta	53.00	103.50	21,700	160	OxA-6191
213	Generalka	55.00	159.15	21,750	150	GIN-5299B

Table 1 (*continued*)

No.	Site name, location, layer no.	Latitude, N	Longitude, E	^{14}C date, BP	Sigma (± σ)	Lab code and no.
214	Popigay River	72.40	106.00	22,000	200	GIN-5574
215	Onot River[13]	52.72	102.00	22,090	150	AA-38039
216	Shestakovo	55.64	88.00	22,240	185	SOAN-3612
217	Shestakovo	55.64	88.00	22,290	125	SOAN-1380
218	Wrangel Island	71.00	179.00	22,400	300	GIN-8259
219	Wrangel Island	71.00	179.00	22,400	200	GIN-8257
220	Shestakovo	55.64	88.00	22,410	200	LU-104
221	Kiya River	55.64	88.00	22,450	200	SOAN-1467
222	Tesa River	57.30	112.00	22,480	420	SOAN-4416
223	Shestakovo[14]	55.64	88.00	22,500	280	SOAH-4177
224	Shestakovo[14]	55.64	88.00	22,750	160	GrA-15880
225	Baskura Peninsula	74.03	100.00	22,750	150	GIN-3089
226	Tavda River	57.68	62.20	22,860	410	SOAN-4802
227	Malta	53.00	103.50	22,900	240	GIN-8888
228	Shestakovo	55.64	88.00	22,990	170	SOAN-1386
229	Tyung River	67.35	116.00	23,100	200	GIN-3232
230	Shestakovo	55.64	88.00	23,330	110	GrN-13235
231	Boderbo-Tarida River	73.06	102.16	23,500	300	GIN-2763a
232	Middle Angara River	59.00	101.30	23,600	200	GIN-5886
233	Uspenka	54.87	70.50	23,670	410	KIGN-397f
234	Kudelin Kluch	55.12	84.24	23,760	245	SOAN-3634
235	Sabler Cape	74.50	102.00	23,800	400	GIN-1296B
236	Faddeevsky Island	75.26	144.00	23,940	150	GIN-8244
237	Kular	70.50	134.23	24,000	1100	GIN-7166
238	Trautfetter River	75.50	100.50	24,170	110	Beta-148639
239	Sobo-Sise Island[10]	72.47	128.42	24,400	650	IM-835
240	Biya River	52.63	85.67	24,400	650	SOAN-119
241	Kaverga River	57.23	112.25	24,600	730	SOAN-4422
242	Achinsk	56.25	90.42	24,650	340	SOAN-4401
243	Batpak	50.50	72.75	24,650	305	SOAN-2712
244	Baskura Peninsula	73.04	100.00	24,900	500	GIN-2160
245	Oktyabrskoi Revolutsii Island[15]	79.52	96.92	24,910	200	LU-749A
246	Oktyabrskoi Revolutsii Island[15]	79.52	96.92	24,960	210	LU-749B
247	Uralovka	52.45	128.11	25,040	200	GrA-13506
248	Pyasina River	72.50	87.00	25,100	500	LE-612
249	Faddeevsky Island	75.26	144.00	25,180	150	GIN-8227
250	Faddeevsky Island	75.26	144.00	25,200	180	GIN-8246
251	Laptev Sea Coast	70.45	131.00	25,300	600	GIN-3502
252	Yuribey River (Gydan Pen.)	70.30	75.50	25,400	300	GIN-2210
253	Faddeevsky Island	75.26	144.00	25,540	170	GIN-8532
254	Malta	53.00	103.50	25,700	260	OxA-6190
255	Faddeevsky Island	75.25	144.00	25,800	200	GIN-4710B
256	Sopochnaya	72.84	106.75	25,800	130	Beta-148634
257	Chekurovka	71.05	127.30	26,000	1600	Mo-215
258	Baskura Peninsula	74.28	101.58	26,100	170	Beta-148665
259	Bolshaya Balakhnya River	73.58	100.55	26,200	150	GIN-11127
260	Mingyuegou	43.11	128.91	26,560	550	WB78-41
261	Lopatka Peninsula	71.83	150.00	26,680	200	GIN-8237
262	Zhalainuoer	49.35	117.58	26,695	1300	PV-0175
263	Bolshaya Balakhnya River	73.53	101.45	26,700	700	GIN-1216
264	Bolshoi Lyakhovsky Island	73.65	143.13	26,860	290	TH-1786
265	Faddeevsky Island	75.26	144.00	27,100	300	GIN-8224
266	Yambuto Lake (Gydan Pen.)	71.02	79.20	27,200	500	GIN-2021b

(continued on next page)

Table 1 (*continued*)

No.	Site name, location, layer no.	Latitude, N	Longitude, E	^{14}C date, BP	Sigma (± σ)	Lab code and no.
267	Logata River	73.08	95.56	27,300	200	GIN-3836
268	Maly Anui River	68.33	161.50	27,470	310	AA-38235
269	Kubalakh River	73.00	97.12	27,500	300	GIN-3929
270	Laptev Sea Coast	70.45	131.00	27,500	300	GIN-3505
271	Irkutsk	53.00	104.40	27,615	2015	SOAN-2222
272	Faddeevsky Island	75.25	144.00	28,000	200	GIN-4710
273	Taymyr Peninsula	73.00	104.00	28,170	210	Beta-148662
274	Western Yamal Peninsula	71.00	66.50	28,300	350	GIN-8545
275	Taymyr Lake	74.32	100.33	28,310	170	Beta-148643
267	Terpyi-Tumus Peninsula	73.55	118.50	28,400	340	GIN-8220
277	Srednekan River	62.45	150.30	28,400	300	GIN-5696
278	Urtuiskoe	50.11	118.00	28,525	200	SOAN-3440
279	Duvanny Yar	68.45	150.45	28,600	300	GIN-3867
280	Faddeevsky Island	75.26	144.00	28,650	350	GIN-8225
281	Tesa River	57.30	112.00	28,670	600	SOAN-4417
282	Lopatka Peninsula	71.83	150.00	28,680	200	GIN-8237
283	Katun River	51.43	85.35	28,730	995	SOAN-2301
284	Shrenk River	75.15	98.00	28,800	600	GIN-952
285	Kuznetsky Basin	54.35	86.21	28,870	600	SOAN-2026
286	Zhoujiayoufang	44.76	126.53	28,880	1220	WB78-45
287	Anabarka River	72.40	106.00	28,900	300	GIN-5073
288	Kotelny Island	75.30	140.00	29,020	190	LU-1791
289	Faddeevsky Island	75.25	144.00	29,100	400	GIN-4330
290	Faddeevsky Island	75.25	144.00	29,100	1000	GIN-4711
291	Yamal Peninsula	67.10	68.00	29,300	300	GIN-6386A
292	Anabar River	72.15	113.30	29,400	400	GIN-3310
293	Matuda (Taymyr Lake)	72.12	96.03	29,500	300	GIN-2155
294	Sanga-Yuryakh River	64.00	126.00	29,500	3000	T-170
295	Tyung River	67.35	116.00	29,600	500	GIN-3234
296	Faddeevsky Island	75.26	144.00	29,700	250	GIN-8260
297	Sokhonto	69.18	69.88	29,700	1000	AA-27380
298	Lopatka Peninsula	71.83	150.00	29,900	300	GIN-8236
299	Talalakh Lake	73.07	106.83	29,990	280	Beta-148635
300	Terpyi-Tumus Peninsula	73.55	118.50	30,000	300	GIN-8218
301	Bolshoy	56.00	159.75	30,000	300	GIN-3415
302	Gyda River	70.30	77.30	30,250	1800	T-298
303	Khomus-Yuryakh River	71.16	153.45	30,400	300	GIN-6023a
304	Borgo-Tokur River	71.00	117.01	30,600	1240	SOAN-3030
305	Bolshaya Balakhnya River	73.60	100.50	30,850	200	GIN-11130a
306	Talalakh Lake	73.07	106.83	30,890	290	Beta-148637
307	Shalaurov Cape	73.22	143.58	31,000	1000	MAG-425
308	Kamenka 1	51.87	108.15	31,060	530	SOAN-3133
309	Enmynveem River	66.30	173.70	31,100	900	MAG-1000B
310	Enmynveem River	66.30	173.70	31,370	900	MAG-1000A
311	Faddeevsky Island	75.26	144.00	31,400	300	GIN-8226
312	Yekaryakha River	71.55	80.66	31,500	1000	T-298
313	Lower Lena River	70.00	125.00	31,500	2000	T-170(3)
314	Geographical Society Cave[16]	42.87	133.00	31,500	980	SOAN-4067
315	Lower Keinguveem River	69.60	164.80	31,530	420	GIN-8240
316	Geographical Society Cave[16]	42.87	133.00	31,550	600	GrA-16819
317	Bolshaya Balakhnya River	73.52	105.08	31,580	240	Beta-148644
318	Baikuraturku Lake	74.00	100.08	31,580	330	Beta-148631
319	Berezovka River	67.15	157.30	31,750	2500	T-299
320	Severnaya River	75.50	112.00	31,800	500	GIN-3240a

Table 1 (*continued*)

No.	Site name, location, layer no.	Latitude, N	Longitude, E	^{14}C date, BP	Sigma ($\pm\sigma$)	Lab code and no.
321	Ozernaya Balya	55.45	103.05	31,860	780	SOAN-4251
322	Sualema River	73.00	112.00	31,900	300	GIN-5726
323	Bolshaya Balakhnya River	75.30	105.00	32,000	200	GIN-3117
324	Matuda Peninsula	74.50	102.63	32,000	500	GIN-2151
325	Enmynveem River	66.30	173.70	32,000	3000	MAG-1124
326	Bolshoy Lyakhovski Island[#]	73.30	142.00	32,030	1170	MAG-316A
327	Shchuchya River	67.38	67.87	32,090	480	AA-27371
328	Bolshoy Lyakhovski Island[#]	73.30	142.00	32,100	900	MAG-316
329	Kupchiktakh Lake	73.60	101.13	32,200	800	GIN-11137
330	Popigay River	72.40	106.00	32,300	400	GIN-5074
331	Zhalainuoer	49.35	117.58	32,430	1700	PV-0170
332	Sabler Cape	74.53	100.50	32,530	270	Beta-148667
333	Geographical Society Cave	42.87	133.00	32,570	1510	IGAN-341
334	Farvaterny	73.67	86.83	32,600	700	GIN-8261
335	Novaya River	72.50	101.58	32,600	280	Beta-148650
336	Sanga-Yuryakh River	64.00	126.00	32,650	2500	T-170
337	Taymyr Peninsula	73.00	103.00	32,750	280	Beta-148632
338	Enmynveem River[¥]	66.30	173.70	32,810	720	MAG-1001A
339	Arylakh Lake	74.43	107.58	32,840	290	Beta-148641
340	Pirkanaivayam River	68.03	166.00	32,850	900	MAG-1000
341	Enmynveem River[¥]	66.30	173.70	32,890	1200	MAG-1001
342	Geographical Society Cave[16]	42.87	133.00	33,000	1000	GrA-16839
343	Shalaurov Cape	73.22	143.58	33,100	2000	MAG-639
344	Geographical Society Cave[16]	42.87	133.00	33,420	460	AA-37183
345	Gyda River	70.30	77.30	33,500	1000	T-298(g)
346	Lopatka Peninsula	71.83	150.00	33,600	500	GIN-8233
347	Duvanny Yar	68.45	150.45	33,800	500	GIN-3861
348	Mingyuegou	43.11	128.91	34,310	1850	WB78-42
349	Kotelny Island	75.00	138.00	34,400	400	GIN-8254
350	Bykovskaya Channel	72.25	127.00	34,450	2500	T-171
351	Faddeevsky Island	75.26	144.00	34,500	500	GIN-8247
352	Shchuchya River	67.10	68.00	34,500	300	GIN-3861
353	Mus-Khaya[17]	70.08	135.33	34,600	470	GIN-8711
354	Duvanny Yar	68.45	150.45	34,700	400	GIN-4434
355	Logata River	73.08	96.03	35,000	500	GIN-3821
356	Laptev Sea Coast	70.45	131.00	35,000	300	GIN-3503
357	Faddeevsky Island	75.26	144.00	35,210	500	GIN-8243
358	Mus-Khaya[17]	70.08	135.33	35,400	2000	AA-27373
359	Gyda River	70.30	77.30	35,500	1100	T-298
360	Bykovskaya Channel	72.25	127.00	35,800	1200	T-171(g)
361	Belkovsky Island	75.63	135.83	35,800	700	GIN-8223
362	Mokhovaya River	72.00	85.30	35,800	2700	T-169(3)
363	Terekhtyakh River[§]	68.58	147.08	35,830	630	LU-504
364	Anabar-Olenek watershed	73.60	117.00	35,900	500	GIN-8262
365	Faddeevsky Island	75.26	144.00	36,000	500	GIN-8238
366	Nikolka	55.00	159.00	36,000	500	GIN-3425
367	Logata River	73.08	96.03	36,200	500	GIN-3822
368	Shandrin River	71.20	150.30	36,450	420	SOAN-1005
369	Anabarka River	72.40	106.00	36,600	500	GIN-5751
370	Faddeevsky Island	75.26	144.00	36,700	500	GIN-8243a
371	Bolshaya Balakhnya River	75.30	105.00	36,800	500	GIN-3122
372	Mokhovaya River	72.00	85.30	36,950	4300	T-169
373	Arylakh Lake	74.44	107.58	36,950	450	Beta-148630

(continued on next page)

Table 1 (*continued*)

No.	Site name, location, layer no.	Latitude, N	Longitude, E	^{14}C date, BP	Sigma (± σ)	Lab code and no.
374	Semiriskay River	72.00	110.55	37,000	500	GIN-5750
375	Popigay River	72.75	108.00	37,080	460	Beta-148666
376	Khatanga River	72.30	104.30	38,000	1500	GIN-942
377	Logata River	73.08	96.03	38,300	600	GIN-3817
378	Bolshaya Balakhnya River	75.30	105.00	38,400	700	GIN-3118
379	Kandabaevo	50.90	108.48	38,460	1100	SOAN-1625
380	Lower Keinguveem River	69.60	164.80	38,500	900	GIN-8250
381	Boderbo-Tarida River	73.06	102.16	38,500	600	GIN-3136
382	Boderbo-Tarida River	73.06	102.16	38,500	500	GIN-2763B
383	Bolshaya Balakhnya River	73.53	100.48	>38,600		GIN-11128
384	Nemu-Dika-Tarida River	73.08	98.75	38,800	400	GIN-3476
385	Trautfetter River	75.63	101.80	38,800	1300	GIN-1491
386	Xietian	45.00	127.60	38,800	3500	AECV-1405c
387	Logata River	73.08	96.03	38,900	600	GIN-3831
388	Arylakh Lake	74.45	107.58	39,050	580	Beta-148664
389	Kuznetsky Basin	54.12	86.38	39,090	2440	SOAN-2027
390	Bolshaya Balakhnya River	75.30	105.00	39,100	1000	GIN-3120/P
391	Bolshaya Balakhnya River	75.30	105.00	39,200	700	GIN-3121/P
392	Baikura-Neru Bay (Taymyr Lake)	74.05	93.10	39,300	500	GIN-3071
393	Bolshaya Balakhnya River	73.60	100.55	39,300	600	GIN-11127a
394	Oktyabrsky	53.00	128.68	39,340	1170	GrA-13487
395	Laptev Sea Coast	70.45	131.00	39,400	1000	GIN-3517
396	Trautfetter River	75.50	100.50	39,560	910	Beta-148638
397	Kirgilyakh River[†]	68.45	158.30	39,570	870	LU-718A
398	Kirgilyakh River[†]	68.45	158.30	39,590	770	LU-718B
399	Kimitina River	56.30	160.00	39,600	1600	GIN-3411
400	Xietian	45.00	127.60	39,600	3000	AECV-1407c
401	Boderbo-Tarida River	73.06	102.16	39,800	600	GIN-3135
402	Anabar Gulf	73.00	113.35	40,100	500	GIN-5726A
403	Bolshaya Balakhnya River	73.53	100.48	40,200	600	GIN-11134
404	Logata River	73.08	96.03	40,200	600	GIN-3804
405	Xietian	45.00	127.60	40,200	3500	AECV-1406c
406	Anabarka River	72.40	106.00	40,300	400	GIN-5025
407	Bolshaya Lesnaya Rassokha River[£]	72.25	100.92	>40,340		LU-750
408	Shandrin River[$]	71.20	150.30	40,350	880	LU-595
409	Engelgardt Lake	75.10	110.30	40,500	800	GIN-1818/P
410	Sabler Cape	74.53	100.50	40,560	700	Beta-148645
411	Polovinka	55.00	159.00	40,600	600	GIN-3407
412	Kirgilyakh River[€]	68.45	158.30	40,600	700	MAG-366A
413	Arylakh Lake	74.46	107.58	40,790	970	Beta-148648
414	Gofman	74.60	101.20	40,800	2000	GIN-1835
415	Kirgilyakh River[€]	68.45	158.30	41,000	1100	MAG-366B
416	Kirgilyakh River[€]	68.45	158.30	41,000	900	MAG-576
417	Khabarovsk	48.50	135.08	>41,000		AA-38040
418	Novoaleksandrovka	50.03	128.27	41,000	4000	AA-37112
419	Belaya River	52.50	103.10	41,100	1500	GIN-7707
420	Malta	53.00	103.50	41,100	1500	GIN-7711
421	Boderbo-Tarida River	73.06	102.16	41,200	1000	GIN-2744B
422	Shaitan Lake	72.47	98.03	41,400	2000	GIN-3941
423	Novaya River	72.52	101.58	41,580	1190	GrA-17439
424	Shandrin River[$]	71.20	150.30	41,750	1290	LU-505
425	Anabarka River	72.40	106.00	41,900	800	GIN-5224
426	Tavda River	59.00	64.00	41,900	800	GIN-5337
427	Ushlep, layer 8	52.85	86.68	>42,000		SOAN-5045

Table 1 (*continued*)

No.	Site name, location, layer no.	Latitude, N	Longitude, E	^{14}C date, BP	Sigma (± σ)	Lab code and no.
428	Berelekh	70.55	149.05	>42,000		LU-1112
429	Ust-Izhul	55.22	91.65	>42,200		AECV-1939C
430	Bolshoy Khomus-Yuryakh River	71.16	153.45	42,400	800	GIN-6310
431	Bolshoi Lyakhovsky Island	73.32	141.38	42,700	1300	GIN-8813
432	Massonov River	72.30	104.30	42,800	800	GIN-3946
433	Dyagyylakh-Sis Island[18]	72.32	127.17	>43,000		IM-835
434	Terekhtyakh River[§]	68.58	147.08	>43,000		IM-667
435	Malta	53.00	103.50	43,100	2400	OxA-6189
436	Arylakh Lake	74.42	107.58	43,160	1280	Beta-148668
437	Amudai River	73.00	119.00	43,200	400	GIN-6100
438	Baikura-Neru Bay	74.05	93.10	43,500	1000	GIN-3072
439	Arylakh Lake	74.42	107.58	43,500	1000	GrA-17499
440	Druzhinikha	56.78	93.52	43,580	8800	LE-4894
441	Chersky	68.45	161.15	43,700	800	GIN-3849
442	Berezovskaya River	67.15	157.30	44,000	3500	T-299
443	Sanga-Yuryakh River	64.00	126.00	44,000	3500	T-170
444	Terekhtyakh River	68.58	147.08	44,540	1900	LU-1050
445	Kheta River	70.83	97.00	45,000	1000	GIN-766
446	Urtuiskoe	50.11	118.00	>45,000		SOAN-3442
447	Ust-Izhul	55.22	91.65	>45,000		SOAN-3334
448	Krasny Yar	55.08	82.50	>45,000		SOAN-3465
449	Tesa River	57.30	112.00	>45,000		SOAN-4415
450	Bolshaya Lesnaya Rassokha River[£]	72.25	100.92	>45,000		MAG-369
451	Bolshoi Kuduskei River	58.48	114.87	>45,000		SOAN-4421
452	Kheta River	71.45	100.00	45,000	1000	GIN-766
453	Amudai River	73.00	119.00	45,500	1200	GIN-6105
454	Achchagy-Allaikha River	69.00	147.30	46,100	1000	GIN-3206
455	Baikura-Neru Bay	74.05	93.10	46,100	1200	GIN-3073
456	Kolyma River	68.00	156.00	46,100	1000	GIN-3206
457	Kaverga River	57.23	112.25	>47,000		GIN-10913
458	Kaverga River	57.23	112.25	47,500	1600	GIN-8981
459	Popigay River	72.80	108.00	47,660	1650	Beta-148669
460	Bolshaya Balakhnya River	75.30	105.00	47,900	1600	GIN-3118a
461	Alei River	52.58	83.00	47,980	1400	SOAN-4199
462	Vacha River	58.48	114.87	>48,000		GIN-9523
463	Mamakan River	57.80	114.03	>48,000		GIN-9066
464	Kuznetsky Basin	54.35	86.21	48,090	2720	SOAN-2025
465	Arylakh Lake	74.42	107.58	>49,210		Beta-148649
466	Nekui River	73.00	120.00	>49,500		GIN-6101
467	Baikura-Neru Bay	74.05	93.10	>49,500		GIN-3080
468	Bolshaya Balakhnya River	75.30	105.00	>49,500		GIN-3092a
469	Maimecha River	70.83	101.00	49,700	1100	GIN-689
470	Lower Lena River	70.00	125.00	>50,000		GIN-359
471	Tirekhtyakh River	69.30	147.15	>50,000		SOAN-813
472	Duvanny Yar	68.45	150.45	>50,000		GIN-3866
473	Anabarka River	72.40	106.00	>50,000		GIN-5731
474	Chersky	68.45	161.15	>50,000		GIN-3848
475	Aprelsky	53.50	126.27	>50,000		GrA-13484
476	Dyagyylakh-Sis Island[18]	72.32	127.17	50,400	1300	GIN-4114
477	Boderbo-Tarida River	73.06	102.16	>52,700		GIN-2764b
478	Duvanny Yar	68.45	150.45	>53,000		GIN-3857
479	Tirekhtyakh River	69.30	147.15	>53,170		LU-1058
480	Bolshaya Lesnaya Rassokha River[£]	72.25	100.92	>53,170		LU-1057

[1–18]Dates were obtained on the same sample, divided into parts; [*,#,¥,§,†,$,£,€]dates were obtained on the same carcass.

University of Arizona, Tucson, AZ, USA (AA; 17 values, 3.5%); the Northeastern Interdisciplinary Research Institute, Far Eastern Branch of the Russian Academy of Sciences, Magadan, Russia (MAG; 16 values, 3.3%); Norwegian University of Science and Technology, Trondheim, Norway (T; 15 values, 3.1%); Centre for Isotope Research, University of Groningen, Groningen, the Netherlands (GrN, GrA; 12 values, 2.5%); Oxford Radiocarbon Accelerator Unit, University of Oxford, Oxford, UK (OxA; 8 values, 1.6%); Institute of Permafrost Studies, Siberian Branch of the Russian Academy of Sciences, Yakutsk (IM; 5 values, 1.0%); Institute of the History of Material Culture, Russian Academy of Sciences, St.-Petersburg, Russia (LE; 4 values, 0.8%); Alberta Environmental Center of Vegreville, Vegreville, Alberta, Canada (AECV; 4 values, 0.8%); Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing, China (PV; 3 values, 0.6%); University of Utrecht, Utrecht, the Netherlands (UtC; 3 values, 0.6%); Institute for Preservation Technology of Cultural Relics, Beijing, China (WB; 3 values, 0.6%); Kazakh Institute of Geological Sciences, Kazakh Academy of Sciences, Alma-Ata, Kazakhstan (KIGN; 2 values, 0.4%); State Scientific Center for Environmental Radiogeochemistry, Kiev, Ukraine (Ki; 2 values, 0.4%); Institute of Archaeology, Chinese Academy of Social Sciences, Beijing, China (ZK; 2 values, 0.4%); University of Uppsala, Uppsala, Sweden (Ua; 1 value, 0.2%); Christian-Albrechts University, Kiel, Germany (KIA; 1 value, 0.2%); Pacific Institute of Geography, Far Eastern Branch of the Russian Academy of Sciences, Vladivostok, Russia (TIG; 1 value, 0.2%); Institute of Ecology of Plants and Animals, Ural Branch of the Russian Academy of Sciences, Ekaterinburg, Russia (IERZH; 1 value, 0.2%); Institute of Geochemistry, Russian Academy of Sciences, Moscow, Russia (Mo; 1 value, 0.2%); Tohoku University, Sendai, Japan (TH; 1 value, 0.2%); and Institute of Geography, Russian Academy of Sciences, Moscow, Russia (IGAN; 1 value, 0.2%).

Most of the ^{14}C dates presented in this review have been produced in Russian laboratories located in Moscow, Novosibirsk, and St.-Petersburg (ca. 73%), using the liquid scintillation counting technique. The main technique of collagen extraction for bone dating, applied in Russian laboratories since the late 1960s, is the dissolution of the mineral part of the bone in weak hydrochloric acid (HCl) (Arlsanov, 1987, pp. 137–143; Arslanov and Svezhentsev, 1993; Sulerzhitsky, 1997; also see description in Vasil'ev et al., 2002, pp. 505–507). It is well-known that collagen in mammalian bones exists in the form of fibrils, organized along with the mineral part of the bone, hydroxyapatite, as lamellae (cf. Lyman, 1994, pp. 72–78). The general idea of our extraction technique is that slow dissolution of the mineral part of whole pieces of bone in diluted HCl makes it possible to extract non-contaminated collagen, and to see the degree of preservation of the initial fibre-like internal collagen structure after demineralization. This is different from Longin's (1971) widely accepted technique of collagen extraction, where bone material is powdered before demineralization.

Pieces of bone 10–20 cm long, cleaned from any surface compounds, are demineralized with a 5% HCl solution (the proportion is 7–8 l of solution for 1 kg of bone) in a temperature of +2–3 °C, usually in a refrigerator. As the surface layer becomes soft, it is scraped off with a knife once every few days, and the demineralization continues until the complete dissolution of the mineral part of bone is finished; this process can sometimes take 1–2 weeks. Finally, the extracted gelatin-like collagen is thoroughly washed with distilled water. In order to remove the humic acids, the collagen is treated with an 0.1 N solution of sodium base (NaOH) for several hours. Sometimes humic acids are removed by centrifuging (acceleration of $2500–3000 \times g$). As to the probable bacterial contamination, remains after the collagen extraction, repeated washing with distilled water allows the removal of any possible bacteria (L.D. Sulerzhitsky, pers. comm. 2000). The remaining collagen is again washed with distilled water, dried, and carbonized by heating in an 800 °C oxygen-free environment. To remove the phosphorous compounds, the carbonized collagen is treated with a mixture of nitric acid (HNO_3) and HCl (“aqua regia”). Finally, the cleaned collagen is washed with distilled water, dried, and used for benzene preparation.

The reliability of ^{14}C dates made on bone is a complex problem under continuous discussion (cf. Taylor, 1997, pp. 87–91). There is clear skepticism in some sources about the accuracy of bone ^{14}C dates performed in Russian laboratories (cf. Goebel, 1993, pp. 139–140). However, we are quite confident that the technique of collagen extraction developed in Russia is very reliable. Several examples of the reliability of such collagen extraction may be found in Sulerzhitsky (1997, pp. 186–188). One of the best cases is the dating of mammoth bones from the Taymyr Peninsula. These bones were collected from the surface and partly covered with moss. After mechanical removal of the moss and collagen extraction as described above, Late Glacial ^{14}C ages (ca. 12,000 BP) were obtained. This clearly shows that well-preserved collagen is very resistant to any kind of contamination. The reliability of the slow dissolution technique for collagen extraction is also supported by parallel dating of the same pieces of bone in Russian (Moscow, Geological Institute; Novosibirsk, Institute of Geology; and St.-Petersburg, State University) and in U.S. laboratories (NSF-Arizona AMS Facility and Beta Analytic) (Vartanyan et al., 1995; Vasil'chuk et al., 2000; MacPhee et al., 2002), as well as in European laboratories (Centre for Isotope Research, University of Groningen) (Kuzmin et al., 2001a,b).

Thus, the extracted collagen and ^{14}C dates run on it appear to be very reliable, and there are no serious arguments so far against the accuracy of the cold HCl extraction technique. The key issue is that if collagen is already degraded before sampling, there is no way to obtain reliable material for dating, even when separate amino acids are being used as a source of radiocarbon (cf. Stafford et al., 1991). As one can observe after bone demineralization with cold HCl, well-preserved collagen keeps the fibre-like structure unlike the degraded collagen which usually has an 'amorphic' appearance.

3. Results of ^{14}C dating of mammoths in northern Asia

As of early 2003, about 530 ^{14}C values, obtained on mammoth remains from Siberia and adjacent territories of northern Asia, were published, and about 480 of them were catalogued and loaded into the Database (Table 1). In total, they represent about 230 localities from all over northern Asia (Fig. 1). The areas with the most abundant ^{14}C dates include the Taymyr Peninsula, Wrangel Island, the Gydan and Yamal Peninsulas, the Upper Yenisei River basin, and the Arctic coast of Yakutia. In some areas, the number of mammoth ^{14}C dates is rather small, such as central Western and Eastern Siberia, the Transbaikal, and the Russian Far East (Amur River basin, Sakhalin Island, and Primorye).

There are two latitudinal 'belts' with the highest concentration of ^{14}C dates: (a) in the Arctic and (b) in the southern part of both Western and Eastern Siberia (Fig. 1). However, this does not mean that the mammoth habitat was divided into northern and southern parts. In our opinion, mammoths existed in the Upper Pleistocene in all of northern Asia. Mammoth remains have been found throughout Siberia, in northern Kazakhstan and Mongolia, in northeastern China and North Korea, and on the islands of Sakhalin and Hokkaido (Vangengeim, 1977; Krasnov, 1984; Baryshnikov and Markova, 1992; Markova et al., 1995). The lack of ^{14}C dates from the regions mentioned above is therefore related to the poor degree of sample collection and dating. Recently, significant progress in ^{14}C dating of mammoth has been achieved in several areas with a previous deficit of mammoth ^{14}C dates (Orlova et al., 2000a).

There are 18 localities in Siberia for which parallel ^{14}C dating of the same sample in two or more different laboratories was performed (Table 1). For most of them, the dates are in good agreement with each other. In some cases, significant differences can be observed in the date series, such as the Lugovskoe locality, ca. 10,820 vs. ca. 13,205 BP (Orlova et al., 2003); the Khorol, ca. 13,750 vs. 17,400 BP; and the Sobo-Sise Island, ca. 14,340 vs. 24,400 BP. For the Lugovskoe locality, the discrepancy may result from sampling of two different individuals as the tooth fragments were collected from a stream bed. In the cases of Sobo-Sise Island and Khorol, the reason for the large discrepancies is not known.

There are eight localities in Siberia with ^{14}C values obtained for the same mammoth carcass (Table 1). Generally, the dates are in good agreement, such as the Jarkov Mammoth (the Bolshaya Balakhnya River), Bolshoi Lyakhovsky Island, Enmynveem River, Kirgilyakh River ("Dima" baby mammoth with well-preserved soft tissues), Bolshaya Lesnaya Rassokha River, Shandrin River, and Kirgilyakh River. However, in the Terekhtyakh series, there is a definite controversy, ca. 35,830 vs. >43,000 BP. It has not

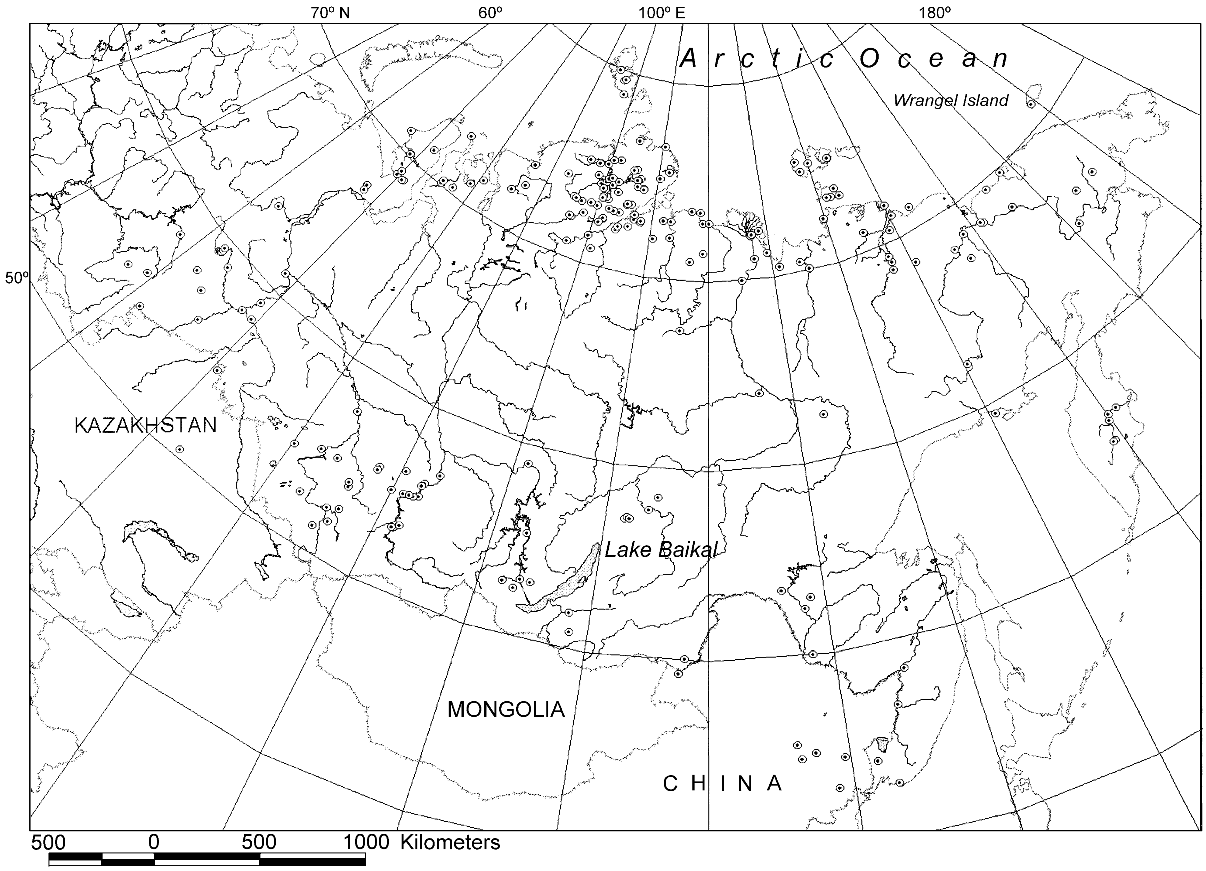

Fig. 1. The position of sites with ^{14}C-dated mammoth remains in northern Asia.

been determined so far why this large difference exists.

The distribution of ^{14}C-dated mammoths in northern Asia shows that these dates correspond to ca. 3700 BP—more than 53,200 BP, for each 2000 ^{14}C years interval (Fig. 2). In total, 499 values (excluding multiple dates for 8 carcasses and for series of dates for the same sample) are being used for statistical calculations. If it is granted that dates are distributed evenly throughout the time span of ca. 3700–53,000 BP, each interval would contain about 19 ^{14}C dates. In several cases, the number of dates exceed this value, particularly at ca. 14,000–12,000 and ca. 22,000–20,000 BP (45 values for each interval), and ca. 30,000–28,000 BP (32 values). Also, for several intervals within the Upper Pleistocene (ca. 54,000–10,000 BP), the number of dates is quite small, such as for the time range of ca. 38,000–36,000 and ca. 46,000–48,000 BP (10 values for each interval). The lowest amount of dates for the Upper Pleistocene corresponds to the interval of ca. 52,000–50,000 BP (1 value). There is no direct correlation between the number of ^{14}C dates made on the mammoth remains and major climatic subdivisions of the Upper Pleistocene of Siberia (see Chapter 4). A definite decrease of dates can be observed in the Holocene, ca. 10,000–2000 BP (the latest date is ca. 3700 BP). There are only 27 values for the Holocene, or 5.6% of the total amount, compared with the Late Glacial, ca. 16,000–10,000 BP, with 88 values (18.4% of the total amount). If we consider only continental Siberia, without Wrangel Island, the number of Holocene ^{14}C dates is even less, i.e. 5 values (1% of the total amount).

Using the ^{14}C age data of mammoths in northern Asia, it is possible to clarify several important prob-

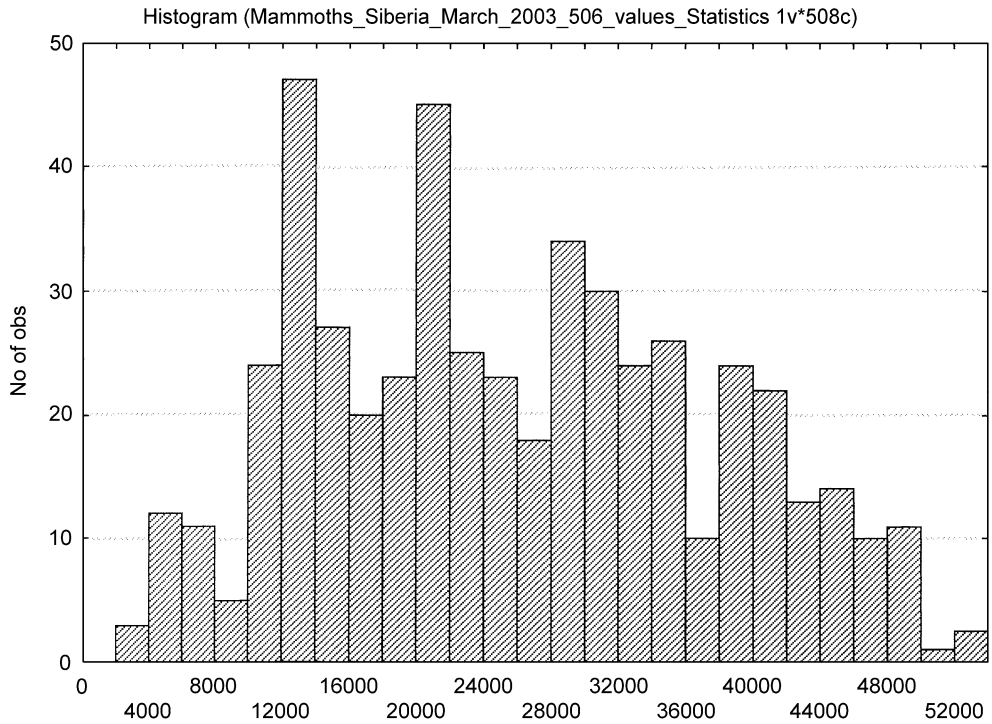

Fig. 2. The histogram of mammoth ^{14}C dates from northern Asia.

lems, including: (1) the mammoth palaeoenvironment for the last Interglacial–Glacial cycle; (2) the spatial-temporal dynamics of mammoth for the last 40,000–50,000 years; (3) inter-relations between mammoth and Palaeolithic humans; and (4) the dynamics of mammoth habitat at the end of its existence, ca. 10,500–9500 BP. In the following chapters, each of these problems will be discussed.

4. Palaeoenvironment of Siberia in the last Interglacial–Glacial cycle

As is widely known, mammoths have inhabited northern Asia since at least the late Middle Pleistocene, i.e. from ca. 300,000 years ago. Ukraintseva (1993) and Ukraintseva et al. (1996, 2001) summarized environmental data for the Late Pleistocene in Siberia, with focus on megafauna living conditions and subsistence. Detailed palaeoenvironmental records in Siberia are available for the last Interglacial–Glacial cycle, including: (1) Last Interglacial (Kazantsevo in Siberia, corresponding to the Eemian in Europe), ca. 130,000–100,000 years ago; and (2) Last Glaciation (Zyryanka in Siberia, corresponding to the Weichselian in Europe, and to the Wisconsin in North America), which consists of an early phase (Ermakovo Glaciation), ca. 100,000–55,000 years ago, a middle phase (Karginsky Interstadial), ca. 55,000–24,000 years ago, and a late phase (Sartan Glaciation), ca. 24,000–10,000 BP (see latest summaries in Velichko, 1984, 1993; Velichko et al., 1997; Chlachula, 2001a,b,c). Mammoths existed throughout northern Asia during these climatic oscillations; an overview of the Siberian environment for this time span follows.

At the Last Interglacial, the major part of Siberia was covered with boreal conifer and birch forests (Velichko, 2002, p. 47) (Fig. 3). A significant territory was occupied by mixed confer-broadleaved forests (up to 60°N), and their northern boundary shifted 700–800 km northward compared to the modern position. Even the modern tundra zone of the Arctic coast in Western Siberia was occupied by light birch

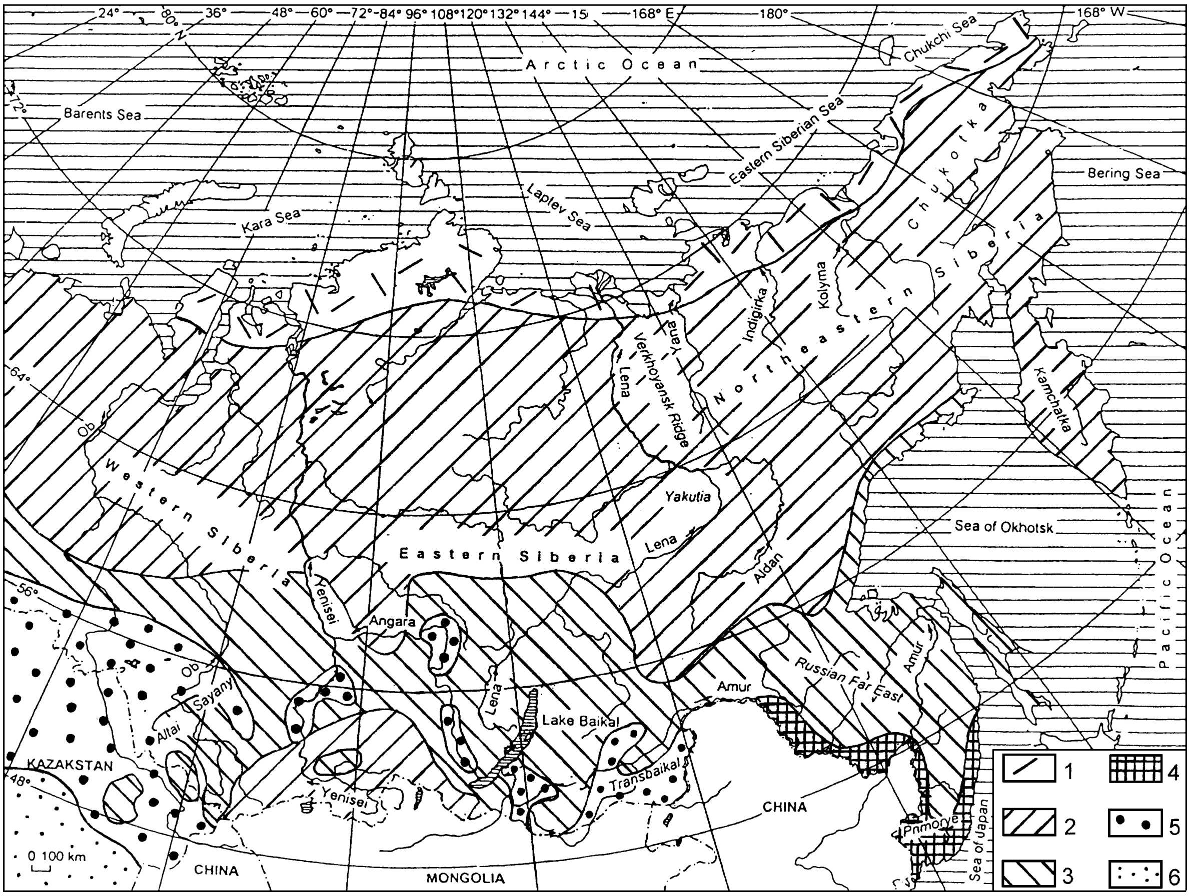

Fig. 3. Palaeoenvironment of Siberia in the Kazantsevo Interglacial (after Velichko, 2002): (1) tundra and forest tundra, (2) boreal (conifers and birch) forests, (3) conifer-broadleaved forests, (4) broadleaved forests, (5) forest steppes, (6) steppes.

and spruce forests and forest tundra. Tundra survived only on the Taymyr and the northern Yamal Peninsulas, and forest tundra occupied the Arctic coast of northeastern Siberia. Forest steppe vegetation was characteristic of the southernmost part of the West Siberian Plain. In the southern Russian Far East, there were pure broadleaved formations (Fig. 3). On the Arctic coast of Siberia, marine sediments with quite thermophilic mollusc and foraminifera faunas are evidence of the Arctic Ocean transgression, with a sea level 10–15 m higher than today.

At the time of the early Last Glaciation, ca. 100,000–55,000 years ago, the climate of Siberia became significantly colder. The continental ice sheet covered the northern part of Western Siberia, and the Taymyr Peninsula and Putorana Plateau in northern Eastern Siberia (Arkhipov et al., 1986a,b). In Western Siberia, a huge ice-dammed lake existed, due to ice sheet blockade of the Ob and Yenisei River run-off to the Arctic Ocean (Arkhipov et al., 1995; Mangerud et al., 2001). The glaciation of central Eastern Siberia and Northeastern Siberia throughout the Upper Pleistocene was of limited scale, mainly represented by mountain-and-valley glaciers in the high ridges (Arkhipov et al., 1986a,b). The main vegetation type in Siberia was tundra, forest tundra, and light conifer forests in the north, and xeric periglacial steppe in the south. In southern Russian Far East, the main vegetation type was light birch-larch forests with some dark conifers (spruce and fir).

The middle phase of the Last Glaciation, ca. 55,000–24,000 years ago, corresponds to climatic amelioration and disappearance of continental ice sheets. Generally, climate of Siberia at this time was cooler than now, with minor fluctuations (see Chapter 6). In northern Western Siberia, the main vegetation type was tundra and forest tundra, and conifer forests occupied the central and southern parts of the West Siberian Plain (Volkov and Orlova, 2000; Volkova, 2001). In Eastern and Northeastern Siberia, tundra and forest tundra in the northern part, and conifer forests with an admixture of birch in the central and southern parts were the main vegetation types. In the southern Russian Far East, mixed conifer-broadleaved forests existed. The marine sediments on the Arctic coast of Siberia below the modern sea level show a transgression of limited scale, with levels of 30–40 m lower than now.

The late phase of the Last Glaciation, ca. 24,000–10,000 BP, is characterized by a significantly colder and drier climate in northern Asia, compared with previous times. Several ice sheet and vegetation reconstructions are available (Grichuk, 1984; Arkhipov et al., 1986a,b; see the latest data in Frenzel et al., 1992; Velichko, 1993). The hypothesis for the existence of a giant continental ice sheet, which covered the entire Arctic coast of Siberia at the Last Glacial Maximum (cf. Grosswald, 1980, 1998), has been challenged repeatedly. The most recent geological data show a quite limited extent of the Sartan ice sheet (Astakhov, 1998;

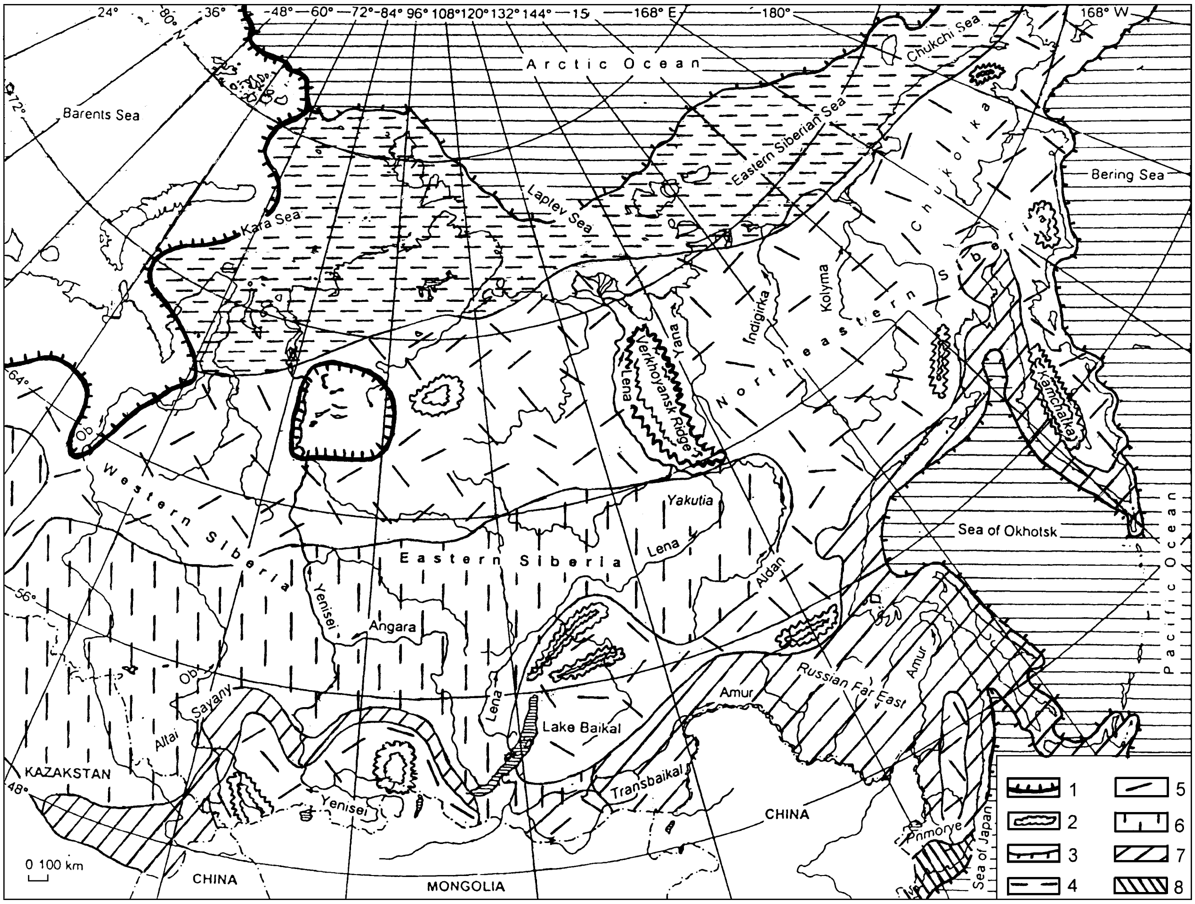

Fig. 4. Palaeoenvironment of Siberia in the Last Glacial Maximum (after Grichuk, 1984): (1) continental ice sheets, (2) mountain-and-valley glaciers, (3) coastline at ca. 20,000–18,000 BP, (4) arctic desert, (5) tundra and forest tundra, (6) periglacial forest steppes, (7) open larch-birch forests, (8) dark-coniferous forests.

Svendsen et al., 1999; Möller et al., 1999; Polyak et al., 2000; Kienast et al., 2001; Forman et al., 2002; Alexanderson et al., 2002).

Other important evidence which contradicts the idea of an extensive ice sheet in northern Siberia is the fact that there are several mammoth remains, ^{14}C-dated to ca. 20,000–17,500 BP, located in the northernmost part of Siberia (the Severnaya Zemlya Islands, the Taymyr and Gydan Peninsulas, Table 1) and not covered with moraines of the Sartan glaciation. Numerous ^{14}C dates of other megafaunal species for the time span of ca. 20,000–18,000 BP from the Taymyr Lake area (MacPhee et al., 2002) support this conclusion. Continental ice sheets were limited to the northern part of Western Siberia, the Putorana Plateau, and the northernmost part of the Taymyr Peninsula. In northeastern Siberia, there were mainly cirque glaciers in the high mountains, with some mountain-and-valley glaciers up to 40 km long (Fig. 4).

The existence of huge ice-dammed glacial lakes in Western and Eastern Siberia, proposed previously (Volkov et al., 1978; Arkhipov, 1998; Arkhipov et al., 1995, p. 198), was recently challenged (Astakhov, 1998, 2001; Zolnikov et al., 2003). Due to sea level regression about 120 m below the present level, wide coastal plains existed on the Arctic coast of Siberia, with the Bering landbridge connecting Siberia and Alaska. Underground permafrost covered almost all of the northern Asian territory. The main vegetation types in Siberia were arctic desert, tundra and forest tundra, and periglacial steppe (in northeastern Siberia the so-called tundra-steppe) (Grichuk, 1984; Tarasov et al., 1999, 2000). In the southern Russian Far East, the vegetation was open birch-larch forests with tundra and forests tundra on the higher elevations, with patches of dark-coniferous forests in refugia (Fig. 4).

5. Mammoth environment in the Late Glacial and the beginning of the Holocene in northern Asia, ca. 15,000–9700 BP

An important issue in the study of mammoth ecology is the environment at the time of the final mammoth extinction. The palaeoenvironmental data available allow us to reconstruct the main vegetation types of the Late Glacial in Siberia and neighbouring territories, especially in the regions where mammoths survived after ca. 15,000 BP (Orlova et al., 2002; Stuart et al., 2002), such as Northeastern Siberia; central Eastern Siberia (or Yakutia); the Russian Far East and adjacent northeastern China (or Manchuria), northern Eastern Siberia (the Taymyr Peninsula and adjacent areas), southern Eastern Siberia (the Angara and the Yenisei River basins), and Western Siberia.

In Northeastern Siberia, mammoths existed on the Chukchi Peninsula in the Late Glacial from ca. 14,400 to 13,000 BP, and in the Kolyma and Yana-Indigirka Lowlands and on the Novosibirsky Islands from ca. 15,000 to 10,400 BP. Over the last two decades, the Late Glacial environments in northeastern Siberia have been studied in depth (see reviews in Lozhkin, 1987, 1993, 1997; Lozhkin et al., 2000a; Anderson et al., 2002). On the Chukchi Peninsula, in the Anadyr River basin the vegetation at ca. 15,000–10,900 BP was represented by shrub tundra (Ivanov et al., 1984; Lozhkin et al., 2000b). In the Amguema River basin, shrub-grass tundra prevailed at ca. 11,600 BP and an increase of tree species is dated to ca. 10,400–9300 BP (Ivanov et al., 1984). In the Chaun Bay area, tundra-steppe conditions existed at ca. 12,200–10,900 BP (Veinsbergs et al., 1976) and at around 10,100 BP the forest tundra prevailed (Ivanov et al., 1984). At ca. 11,000 BP, tree species appeared at the Rautan Island in the Chaun Bay, today covered with tundra vegetation (Kaplina and Lozhkin, 1982).

On the Novosibirsky Islands, tundra-steppe landscapes existed until ca. 12,300 BP, and around this time an increase of birch pollen was recognized in the sediments (Makeev et al., 1989). At ca. 10,500–10,100 BP, the main vegetation type was shrub tundra and the climate was more favourable than today (Ukraintseva et al., 1989). At ca. 9700 BP, pollen of birch, shrub alder, and willow predominate in the spectra (Makeev et al., 1989). On the Lena River mouth, at ca. 12,300–8500 BP tundra with shrub birch was the main vegetation type, with an increase of herbs in the Younger Dryas cooling, ca. 11,000–10,000 BP (Pisaric et al., 2001).

In the Kolyma and Yana-Indigirka Lowlands, arctic tundra vegetation dominated at ca. 15,000–14,000 BP (Sher and Kaplina, 1979, p. 103; Kaplina and Lozhkin, 1982; Giterman, 1985). At ca. 12,500–11,500 BP, the vegetation changed to southern tundra and forest tundra with larch (Lozhkin, 1987), and on the Polousny Ridge to larch forests with shrub alder, tree and shrub forms of birch (Kaplina and Lozhkin, 1982; Giterman, 1985). In the upper Indigirka River basin, tundra dominated until ca. 10,800 BP and after that shrub tundra was the principal vegetation type (Anderson et al., 2002). In the earliest Holocene, ca. 10,400–10,300 BP, the lowlands were covered with forest tundra (Kaplina and Lozhkin, 1982).

In the northern Sea of Okhotsk coastal area and the Upper Kolyma River basin, at ca. 15,000–12,500 BP, grass and shrub-grass tundra dominated (Lozhkin, 1991; Lozhkin et al., 1995a,b, 1996, 2000c; Anderson et al., 1997, 1998). At ca. 12,500–11,500 BP, the vegetation was replaced by shrub birch tundra with larch and, at ca. 10,000 BP, light larch forests appeared in the northern Sea of Okhotsk region.

In general, the vegetation in Northeastern Siberia from ca. 12,500 to 11,500 BP changed from grass and grass-shrub tundra to shrub birch and alder tundra (Lozhkin, 1987, 1997; Lozhkin et al., 2000a). This "Birch Zone" is dated to ca. 12,500–8300 BP in the pollen diagrams of central Northeastern Siberia, and to 12,500–10,500 BP in the southern Chukchi Peninsula (Lozhkin et al., 2000b). It is obvious that the important climatic boundary in Northeastern Siberia, dated to ca. 12,500 BP, reflects the transformation of vegetation cover in this territory (Lozhkin, 1997).

In Yakutia, mammoths existed in the Late Glacial during ca. 14,300–12,500 BP. According to the pollen data from the Dyuktai Cave, where mammoth bone is dated to ca. 12,500 BP, the environment of the central Aldan River basin at ca. 13,000–12,500 BP was represented by grass associations, reflecting a very cold climate (Savvinova et al., 1996). After ca. 12,500 BP, the role of larch increased, strongly indicative of a climatic amelioration. According to studies of lake deposits in central Yakutia (Andreev and Klimanov, 1989; Andreev et al., 1989; Velichko et al., 2002, p. 78), steppe formation prevailed in the Allerød (ca. 11,800–11,000 BP) and the climate was dryer and colder than nowadays. In the Younger Dryas (ca. 11,000–10,300 BP), steppe-like wormwood formations dominated, and forest species disappeared. In general, during the Late Glacial in central Yakutia steppe wormwood associations and light forests with shrubs existed, and a larch-birch forest landscape at the beginning of the Holocene.

In the Far East, the latest mammoths are ^{14}C-dated to ca. 13,800 BP in Primorye, to ca. 12,900 BP in Manchuria, and to ca. 12,600 BP at Kamchatka Peninsula. Throughout the Late Glacial, a gradual increase of dark conifers (spruce and fir) and broadleaved vegetation is apparent, after a dominance of light birch-larch and spruce forests during the Last Glacial Maximum (Korotky et al., 1997). In Primorye, birch-larch forests prevailed at ca. 16,000–15,000 BP; warm events during 15,000–10,000 BP were characterized by an increase of dark conifers in the vegetation composition (Korotky et al., 1997), and an increase of broadleaved species at ca. 13,000–11,000 BP (Shumova and Klimanov, 1989). The cold events at ca. 15,000–13,000 BP, and especially at ca. 11,000–10,000 BP, were characterized by an expansion of light birch-larch forests (Korotky et al., 1997) and forest tundra formations (Shumova and Klimanov, 1989).

In Manchuria, significant warming and moistening began at ca. 13,000 BP. These changes resulted in the retreat of the permafrost boundary to the north, the disappearance of tundra and forest tundra, and a dominance of conifer forests north of 45° N and conifer-broadleaved forests south of 45°N (Liu, 1988; Winkler and Wang, 1993). At ca. 12,000 BP, the main vegetation type was light forests with patches of permafrost in the Dao Xinggan Mountains, with an annual mean temperature 6–10 °C lower than now (Winkler and Wang, 1993). In more southerly territories, such as the Korean Peninsula, temperate conifer forests were replaced by broadleaved formations at ca. 13,000 BP (Verkhovskaya et al., 1992).

On the Kamchatka Peninsula, in the eastern part at ca. 12,000–8000 BP tundra formations predominated (Egorova, 1982). In central Kamchatka, at the Ushki 1 site, arctic tundra vegetation at ca. 14,000–10,000 BP was replaced at the beginning of the Holocene by shrub-moss tundra (Dikov, 1996). Other data also testify that tundra vegetation grew in most of Kamchatka in the Late Glacial (Ivanov, 1976; Ivanov et al., 1984; Bespaly et al., 1982; Stefanovich et al., 1986).

In the northern part of Eastern Siberia (the Taymyr Peninsula), in the Late Glacial, mammoths existed at ca. 14,800–9700 BP. Environmental conditions during this period of time are well-studied (cf. Kind, 1974; Kind and Leonov, 1982; Bardeeva et al., 1980; Nikolskaya, 1980; Nikolskaya and Cherkasova, 1982; Nikolskaya et al., 1980). In the Younger Dryas, at ca. 10,900 BP, the vegetation was represented mainly by tundra with shrub birch and tundra-steppe, and the climate was very cold (Muratova et al., 1993; Andreev et al., 2002). At ca. 10,000 BP and in the Preboreal period of the Holocene, ca. 9300–9100 BP, the amount of trees increased, and forest tundra with spruce and birch appeared around the Lama Lake on the Putorana Plateau (Kind, 1974, pp. 53–55). Forest tundra with spruce, pine, and larch occupied the Maimecha River headwaters, also located on the Putorana Plateau (Bardeeva et al., 1980). The climate of the Taymyr at ca. 9300–9200 BP was warmer and wetter than now (Nikolskaya et al., 1989, p. 143), and the main vegetation type was shrub tundra and forest tundra (Nikolskaya, 1980; Nikolskaya et al., 1980; Nikolskaya and Cherkasova, 1982). It is important to note that larch penetrated to the Novaya River basin (72°35′ N) around 10,500 BP (Belorusova et al., 1987; Ukraintseva, 1990) and to the Lake Labaz area around 9400 BP (Andreev et al., 2002), at the time of climatic amelioration. In the earliest Holocene, the northern limit of forest vegetation was even further north of this area (Belorusova et al., 1987).

In the southern part of Eastern Siberia, mammoths lived in the Late Glacial at ca. 14,700–13,300 BP in the Yenisei River basin, and at ca. 14,700–12,100 BP in the Angara River headwaters. During the time interval of ca. 18,000–14,000 BP, tundra and forest tundra landscapes dominated in these areas (Bezrukova, 1999; Bezkrukova et al., 2000). At about 15,500–14,000 BP, the forestation process began along with gradual climatic amelioration, but most of the territory was still covered with treeless formations represented on the southern Lake Baikal shore by meadow steppe with spruce. In the Younger Dryas (ca. 11,500–11,000 BP), an increase of larch forest has been recognized in an environment of tundra and forest tundra (Bezrukova, 1999; Bezkrukova et al., 2000).

In the Yenisei River basin, around the modern City of Krasnoyarsk at ca. 14,000–13,000 BP, there was steppe vegetation with light spruce and birch forests (Chekha et al., 2000). At ca. 13,000–12,000 BP, forest elements represented by spruce, fir, pine, and birch, increased. In the cooler climate of ca. 12,200–11,800 BP, meadow steppe formations with light spruce forests prevailed. At the next amelioration, ca. 11,800–11,400 BP, spruce forests were the main vegetation type. At ca. 11,400–10,300 BP, cooling caused the dominance of steppe formations with light spruce forests (Chekha et al., 2000).

In the northern part of western Siberia (the Yamal and Gydan Peninsulas), mammoths in the Late Glacial existed during ca. 14,400–10,000 BP. The most complete section with environmental records for this time interval was studied at the Sverdrup Island in the Kara Sea (74°35′ N, 79°30′ E), 120 km offshore the Arctic coast of western Siberia (Tarasov et al., 1995). In the Allerød, ca. 12,000 BP, the island was covered with tundra and shrub birch, and the climate was dryer than today. In the Younger Dryas, ca. 10,500 BP, wormwood and chenopod grasses dominated with an increased role of shrub species, in colder and dryer conditions compared to the Allerød. In the early Preboreal time of the Holocene, ca. 9800 BP, the vegetation of the southern tundra was dominated by shrub birch and heather. The climate was warmer than in the Allerød and the warmest throughout the entire Holocene. At ca. 9700 BP, larch penetrated on the Gydan Peninsula up to 70°N (Ukraintseva, 1990). At ca. 9500 BP, near the modern Igarka town, birch, spruce, and larch grew (Levkovskaya et al., 1970). At ca. 9400 BP, birch remains are known from the southern Yamal Peninsula (Forman et al., 2002).

In the southern and central parts of Western Siberia, mammoths in the Late Glacial existed at ca. 14,300–10,200 BP. According to the study of key sections (cf. Panichev, 1979; Levina et al., 1989; Orlova, 1990; Levina and Orlova, 1993; Volkov and Orlova, 2000; Velichko et al., 2002, p. 78), the Upper Ob River basin in the Bølling (ca. 13,000–12,000 BP) was covered with grass formations on the watersheds, and with spruce and birch forests in the river valleys. The climate was quite warm and wet, probably similar to the modern one. In the Older Dryas (ca. 12,000–11,800 BP), the periglacial steppe dominated, and the climate was cold and dry. In the Allerød (ca. 11,800–11,000 BP), the watersheds of the southern West Siberian Plain were covered with grass steppes, and in the river valleys spruce and birch forests existed. The climate was in general colder than at present. In the Younger Dryas (ca. 11,000–10,200 BP), xeric tundra formations with shrub birch prevailed in cold and dry conditions. At the beginning of the Holocene, ca. 10,000 BP, tundra was replaced by steppe formations with an admixture of pine-birch forest steppe, and the climate was cool and wet.

In the Lower Irtysh River basin, at ca. 15,000–14,000 BP, the northern type of taiga with shrub birch existed; at ca. 12,000 BP—the taiga forests (the Bølling warm event); and at ca. 11,000 BP—forest tundra and tundra (the Younger Dryas cooling) (Krivonogov, 1988). In northern Kazakhstan, at ca. 13,000 BP wormwood steppe dominated, with light coniferous forests on the higher elevations; the climate was cold and dry (Kremenetsky, 1997). At the end of the Late Glacial and in the earliest Holocene, ca. 12,000–9500 BP, the role of trees increased significantly, and the main vegetation types were grass steppes on the watersheds and light birch forests with conifers in the Upper Irtysh River valley. The climate was dry and cool compared with the modern one.

This regional overview thus shows that mammoths in Siberia and adjacent regions existed in the Late Glacial in an environment of tundra and forest tundra. The expansion of tree species, which began at ca. 12,000–10,000 BP, is correlated in general with a sharp decrease of the mammoth habitat (see Chapter 6).

6. Spatial-temporal peculiarities of the mammoth habitat in northern Asia over the last 50,000 years

To reveal the main spatial-temporal patterns of mammoth populations in Siberia and adjacent territories, the period of the last 50,000 years was subdivided into several time intervals, according to palaeoenvironmental changes (Kind, 1974): (1) the Karginsky Interstadial (ca. 50,000–24,000 BP), including: (a) the Early Karginsky warm and cold episodes (50,000–33,000 BP), (b) the Konoshchelye cold episode (ca. 33,000–30,000 BP), and (c) the Lipovka-Novoselovo warm episode (30,000–24,000 BP); (2) the Sartan Glaciation and the Late Glacial (24,000–13,000 BP), including (d) the Early Sartan (24,000–20,000 BP), (e) the Sartan Glacial Maximum (20,000–18,000 BP), and (f) the Late Sartan and initial phase of the Late Glacial (18,000–13,000 BP); and (3) the Late Glacial and the Early Holocene (13,000–9000 BP), including (g) the Bølling-Allerød (13,000–11,000 BP), (h) the Younger Dryas (11,000–10,000 BP), and the earliest Holocene (10,000–9000 BP).

The geographical distribution of the Karginsky (ca. 50,000–24,000 BP) and Early Sartan (ca. 24,000–20,000 BP) mammoth localities appear to have much in common. Mammoths inhabited the whole territory of Siberia and adjacent regions of northern Asia during this time. However, for the Last Glacial Maximum (20,000–18,000 BP) we have only 23 ^{14}C dates (4.8% of the total) derived from 22 localities (Table 1), and these are concentrated mainly in both the High Arctic and the Upper Yenisei River basin, with some localities in Western Siberia (Fig. 5). Mammoth remains are also known from a series of Palaeolithic sites associated with the Last Glacial Maximum such as the Buret site in the headwaters of the Angara River; Kunalei in the Transbaikal; and the Ikhine 2 and Verkhne-Troitskaya sites in Yakutia (Kalmykov et al., 1992; Tseitlin, 1979; Ravsky, 1972) (Fig. 5). Thus, we have enough evidence to suggest that mammoths lived throughout Siberia at the time of Last Glacial Maximum. The distribution of mammoth remains in the Late Sartan (ca. 18,000–13,000 BP) generally is not dissimilar from the Karginsky and Early Sartan time intervals; mammoths continued to occupy essentially the whole territory of Siberia, northeastern China, and northern Kazakhstan.

From approximately 12,000 BP, the distribution pattern of mammoths changed significantly (see Chapter 8 for details). Suitable habitats were substantially reduced in size, and included only the lower part of the Indigirka River basin, the Taymyr Peninsula, the Severnaya Zemlya archipelago, and some areas in the central and southern West Siberian Plain and in the Upper Yenisei River basin (Fig. 6). Finally, in the Early and Middle Holocene, 9000–3700 BP, mammoths existed only on Wrangel Island. These individuals were of a smaller size than the common mammoth species and are frequently referred to as a subspecies, *M. primigenius vrangeliensis* (Averianov et al., 1993).

The distribution patterns of mammoth habitat in the Arctic regions of Siberia in the last 50,000 years, based on numerous ^{14}C dates, were considered by Sulerzhitsky and Romanenko (1997, 1999). They concluded that mammoths inhabited the Taymyr Peninsula since ca. 50,000 BP until ca. 9700 BP, and the Yamal and the Gydan Peninsulas during ca. 35,000–10,000 BP. On the Taymyr Peninsula, there is a clear decrease of mammoth ^{14}C dates at ca. 21,000–15,000 BP, which might mean that mammoths preferred other areas to the Taymyr at the time of the coldest

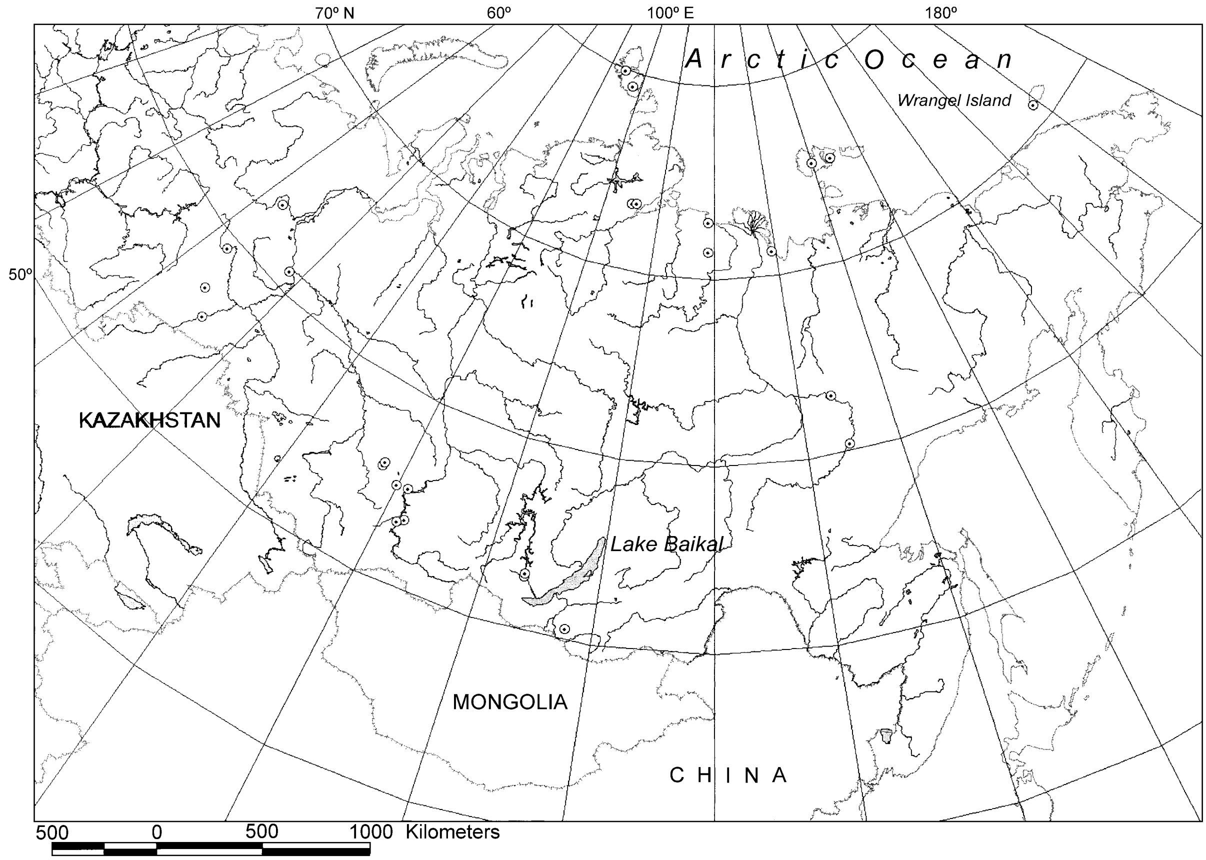

Fig. 5. The position of ^{14}C-dated mammoth remains in Siberia at the time of the Last Glacial Maximum (ca. 20,000–18,000 BP) [plus Bykovsky Peninsula, Buret, Kunalei, Ikhine 2, Verkhne-Troitskaya].

environment in the last 50,000 years. At the Novosibirsky Islands located offshore northern Yakutia, mammoths appeared for the first time at ca. 36,000 BP, and continued to exist until ca. 13,700 BP. Mammoths appear to have occupied the neighbouring Artic coast of Yakutia since ca. 50,000 BP, and did not migrate northward to the modern Novosibirsky Islands until ca. 36,000 BP. On Wrangel Island, the 'normal' sized mammoths appeared for the first time at ca. 22,500 BP, and existed until ca. 12,000 BP; 'small' size mammoths existed from ca. 7700 to 3700 BP. The gap in the mammoth ^{14}C date series between ca. 12,000 BP and ca. 7700 BP may indicate that mammoths did not occupy Wrangel Island in this time interval.

Using the data obtained, we can correlate the number of mammoth ^{14}C dates with climatic events in the Late Glacial. According to general palaeogeographical subdivisions of the Late Glacial in Russia (Zubakov, 1986, pp. 235–243), the interval of ca. 15,000–10,000 BP includes the Krestsy cooling (ca. 15,300–13,800 BP), the Kokorevo warming (ca. 13,800–13,300 BP), the Oldest Dryas cooling (ca. 13,300–12,800 BP), the Bølling warming (ca. 12,800–12,300 BP), the Older Dryas cooling (ca. 12,300–11,800 BP), the Allerød warming (ca. 11,800–11,000 BP), and the Younger Dryas cooling (ca. 11,000–10,300 BP). Using 86 ^{14}C values corresponding to the time ca. 15,000–9700 BP (Table 1, multiple dates are excluded), we can conclude that 15 values belong to the Krestsy event; 15—to the Kokorevo, 12—to the Oldest Dryas, 9—to the Bølling, 10—to the Older Dryas, 6—to the Allerød, 8—to the Younger Dryas, and 11—to the earliest Holocene,

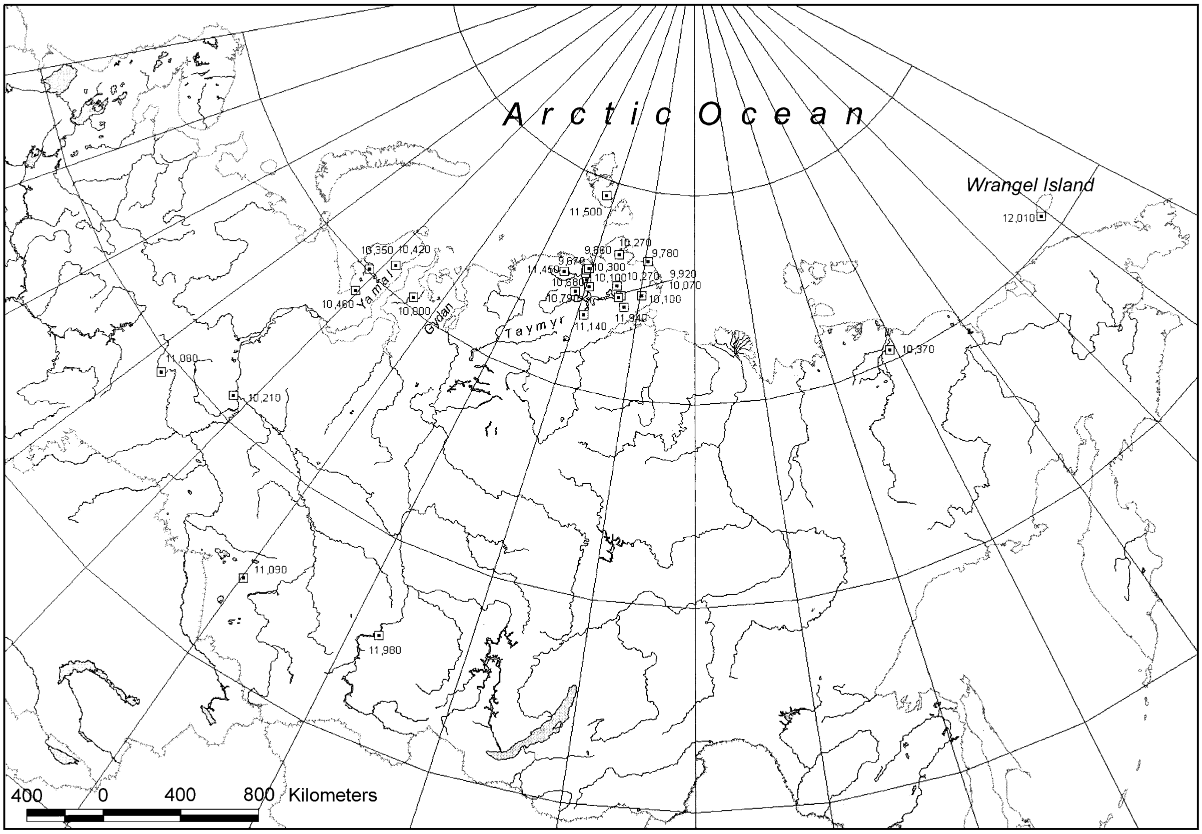

Fig. 6. The position of ^{14}C-dated mammoth remains in Siberia in the Late Glacial (ca. 12,000–10,300 BP) and at the beginning of the Holocene (ca. 10,300–9500 BP).

ca. 10,300–9700 BP. There are 41 (47.7%) and 45 (52.3%) dates which correspond to the warm and cold events, respectively, practically an equal number of ^{14}C dates corresponding to warm and cold events. From this, one might infer that mammoths could have lived in a gradually warming environment, and not simply that a climatic amelioration caused their final extinction in Siberia at the beginning of the Holocene, but rather a combination of factors.

7. The mammoth–human relationship in the Palaeolithic of Siberia

For several decades, the study of the relationship between the Pleistocene megafauna and prehistoric humans has been one of the most important issues in Palaeolithic geoarchaeology (e.g. Klein, 1973; Martin, 1984; Vereshchagin and Baryshnikov, 1984; Soffer, 1985; Stuart, 1991). In Siberia, significant progress in both excavations and ^{14}C dating of the Palaeolithic sites was achieved from the 1950s to the 1990s (e.g. Abramova, 1984, 1989; Derevianko, 1998; Kuzmin and Orlova, 1998; Vasil'ev et al., 2002). Using the data obtained, it is possible to reconstruct the main peculiarities of the process of human colonization of Siberia.

At about 40,000 BP, portions of Siberia were occupied by prehistoric human populations, including the Altai Mountains, the Upper Lena River basin, and the Transbaikal (Kuzmin and Orlova, 1998; Orlova et al., 2000a). By 24,000–20,000 BP, Palaeolithic sites also existed in the Sayan Mountains, the Upper Yenisei River basin, the Angara River basin, the Middle Lena River basin, the Middle Amur River basin, and Primorye. Taking this data into consideration, we also assume that the age of the Yakutian sites associated with the Dyuktai culture (the Ust-Mil-2, for example) is no older than ca. 24,600 BP (Kuzmin and Orlova, 1998; Vasil'ev et al., 2002). At around 13,000 BP, almost the entire region of Siberia, except the lower streams of the Ob, Yenisei, and Lena rivers, was permanently inhabited.

It should be stressed, however, that it is difficult to provide absolute boundaries on the areas occupied by human populations at certain times in the Upper Palaeolithic. Long distance migrations over unoccupied territory were possible, but it is difficult to verify these archaeologically. Two finds of presumably human-modified mammoth bones, at the Duvanny Yar site (lower stream of the Kolyma River) dated to ca. 33,800 BP, GIN-3861 (Sulerzhitsky, 1997, p. 196), and on Wrangel Island dated to ca. 22,400 BP, GIN-8259 (Sulerzhitsky and Romanenko, 1999, p. 255), could be evidences of later Upper Pleistocene episodic human migrations northward from southern and central Eastern Siberia. Thus, in order to be more objective we accept the 'minimal scenario' of the Palaeolithic ecumene (i.e. occupied space) of Siberia, with the help of ^{14}C-dated sites corresponding to particular time intervals.

Analysis of the spatial distribution of the ^{14}C-dated mammoth remains and the Palaeolithic sites during ca. 24,000–20,000 BP demonstrates a long period of coexistence (not less than several thousand years) of human and mammoth populations in a number of regions in Siberia, first of all in the Upper Yenisei and Angara River basins. One can observe similar patterns at ca. 18,000–13,000 BP, when mammoths coexisted with humans in the southern parts of Western and Eastern Siberia, and in Primorye. The Upper Yenisei River basin is the area with the most abundant data for studying the relationship between Palaeolithic humans and mammoths, and it may be chosen as the model region for all of northern Asia.

In the Upper Yenisei River basin, archaeological research has been carried out since the end of the 19th century (see reviews in Abramova, 1991; Astakhov, 1999) and dozens of Palaeolithic sites have been excavated (Abramova, 1991; Vasil'ev, 1992, 1996, 2000; Vasil'ev and Semenov, 1993; Davis, 1998; Lisitsyn, 2000). About 30 of these sites were ^{14}C-dated in the 1960s–1990s (Lisitsyn and Svezhentsev, 1997; Kuzmin and Orlova, 1998; Orlova et al., 1998). Many of the sites contain animal bones and zooarchaeological studies have been undertaken since the 1920s (Gromov, 1932), most actively during the 1960s–1980s (Ermolova, 1978; Abramova, 1991, pp. 26–34; Derevianko et al., 1992; see reviews in Tseitlin, 1979; Vasil'ev, 2000, 2003). Twenty-seven Upper Palaeolithic sites with representative ^{14}C and zooarchaeological records were selected for the study of the human–mammoth relationship (Fig. 7). Three site categories were distinguished: Group 1, with directly ^{14}C-dated mammoth bones; Group 2, with mammoths in the assemblage, and ^{14}C dates on charcoal and bones of animals other than mammoth; and Group 3, without mammoths, and ^{14}C dates on charcoal and animal bones.

Mammoths existed in the Upper Yenisei basin from the middle of the Late Pleistocene, with the earliest ^{14}C dates of >45,000 BP (SOAN-3334) and >42,100 BP (AECV-1939C) at the Ust-Izhul site (Drozdov et al., 1999). A sequence of mammoth ^{14}C dates from the Last Glacial Maximum, ca. 20,000 BP onwards, has been obtained from the Upper Yenisei basin (Sulerzhitsky, 1997; Orlova et al., 2000b). The latest date is 13,260 ± 250 BP (GIN-7538) (Table 1). Eleven Upper Palaeolithic sites in the Upper Yenisei basin have mammoth bones in the assemblages (Fig. 8). The general age range for this group is ca. 24,900–12,900 BP. Five of the 11 sites have direct ^{14}C dates on mammoth remains, ranging in age from ca. 20,100 to ca. 13,300 BP. Seventeen Upper Palaeolithic sites in the Upper Yenisei basin without evidence of mammoth bone utilization are known from approximately the same time range, ca. 25,400–12,200 BP (Fig. 9). Bones of large ungulates, such as reindeer, red deer, bison, horse, wild sheep, and Asiatic wild ass, are the most abundant mammal species at these sites.

One of the sites, Novoselovo 13, have no mammoth bones in layer 1, ^{14}C-dated to ca. 15,000–13,600 BP, although mammoth was identified in layer 3, which has a charcoal ^{14}C date of ca. 22,000 BP. This clearly shows that human–mammoth interaction was complex, and the presence or absence of mammoth bones in an assemblage does not reflect the real importance of mammoth in the Upper Palaeolithic economy. Thus, we have two types of Upper Palaeolithic subsistence in the Upper Yenisei basin, one utilizing mammoth bones and tusks, and the other without utilization of mammoth. However, both types

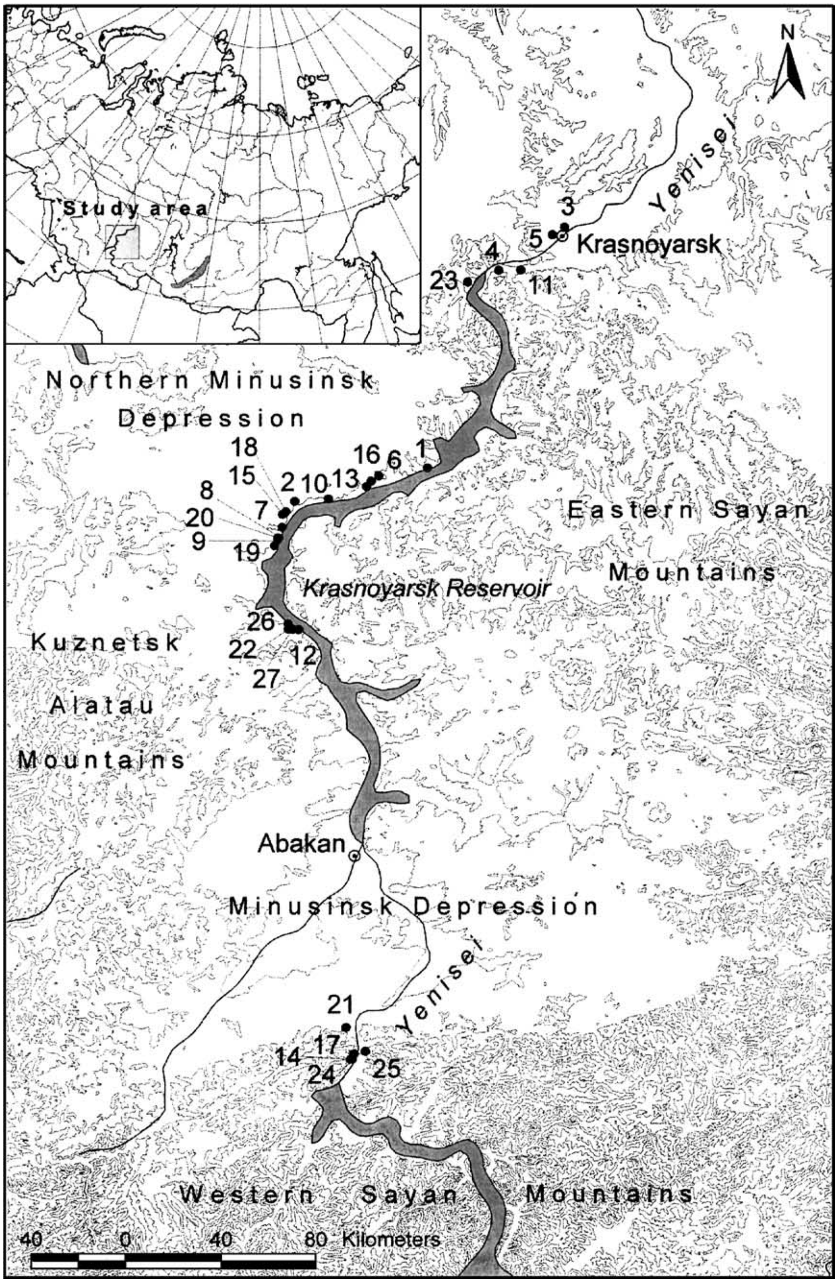

Fig. 7. The Upper Palaeolithic sites in the Upper Yenisei River Basin with zooarchaeological and ^{14}C records. Site Group 1: (1) Shlenka, (2) Tarachikha, (3) Korovy Log, (4) Listvenka, (5) Afontova Gora 2. Site Group 2: (6) Kurtak 4, (7) Novoselovo 13, (8) Kokorevo 4a, (9) Kokorevo 2, (10) Divny 1, (11) Bolshaya Slizneva. Site Group 3: (12) Sabanikha, (13) Kashtanka 1, (14) Ui 1, (15) Novoselovo 6, (16) Kurtak 3, (17) Maininskaya, (18) Novoselovo 7, (19) Kokorevo 1, (20) Kokorevo 4b, (21) Oznachennoye 1, (22) Tashtyk 4, (23) Birusa, (24) Ui 2, (25) Golubaya 1, (26) Tashtyk 2, (27) Tashtyk 1.

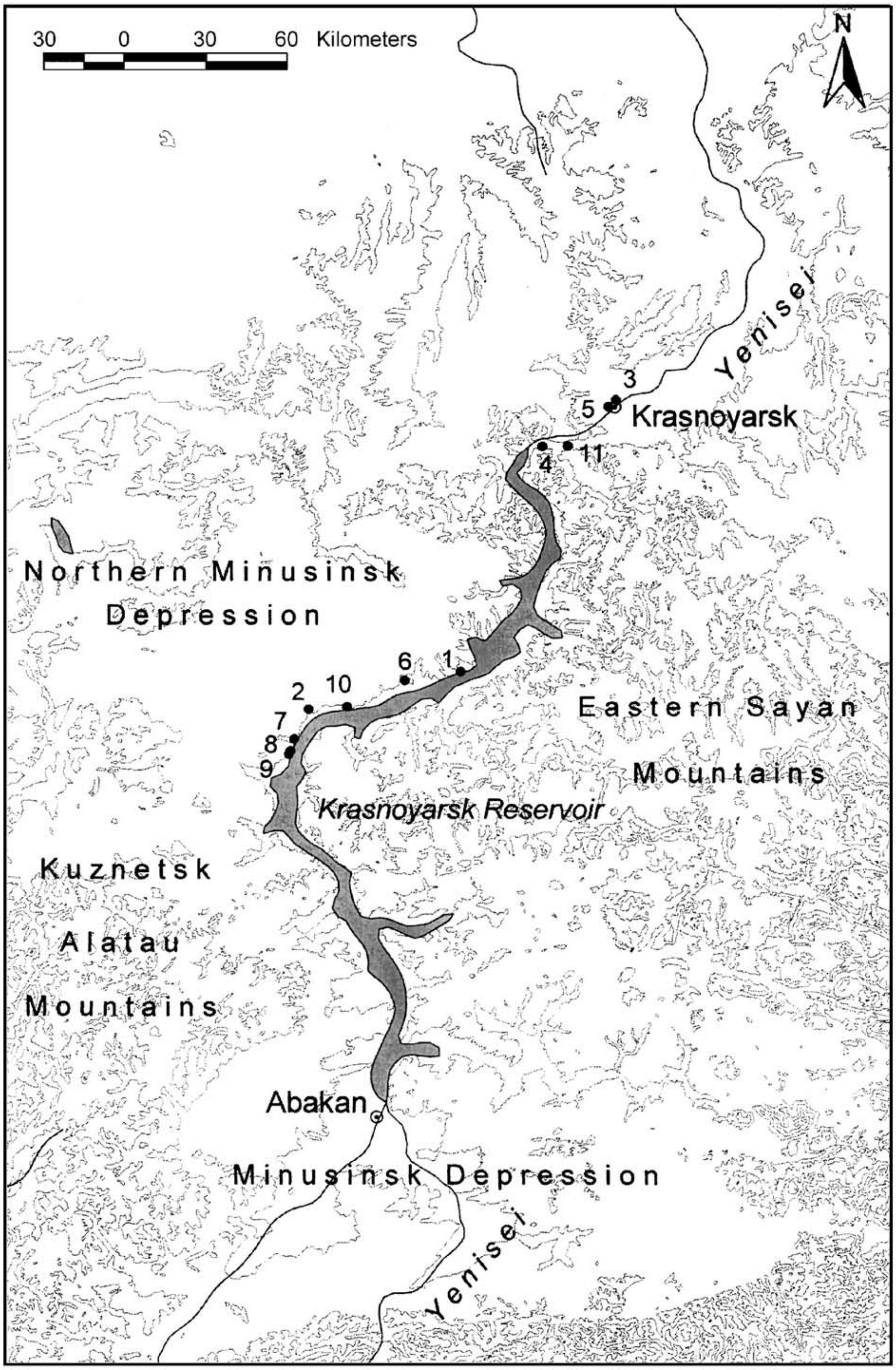

Fig. 8. The Upper Palaeolithic sites with remains of woolly mammoth in the Upper Yenisei River Basin.

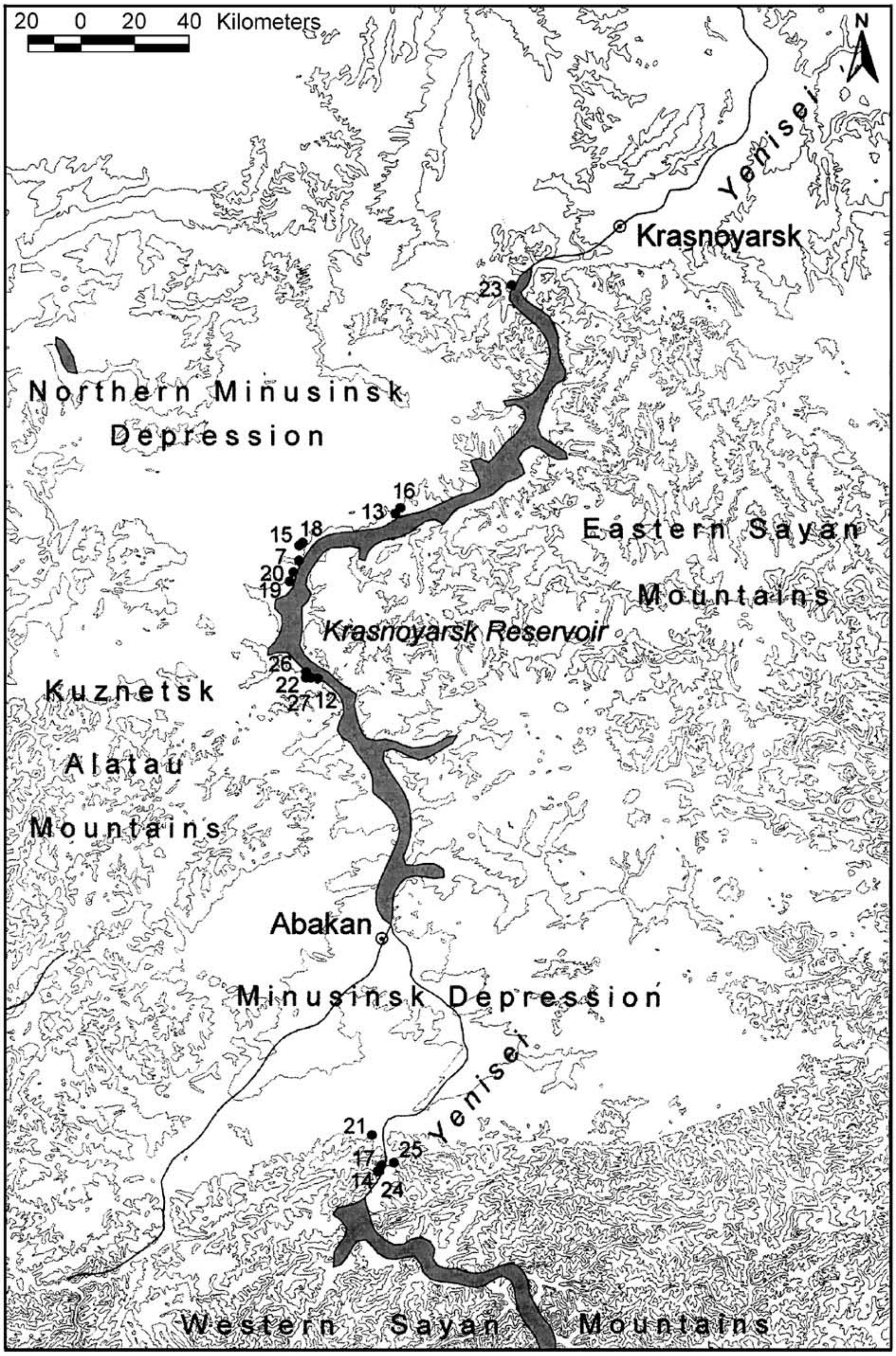

Fig. 9. The Upper Palaeolithic sites without remains of woolly mammoth in the Upper Yenisei River Basin.

are characterized by a dominance of reindeer in the assemblages, with a co-dominance of red deer, bison, horse, wild sheep, Asiatic wild ass, wolf, and hare. The data available demonstrate the spatial-temporal coexistence of mammoth and Upper Palaeolithic humans within the restricted region of the Upper Yenisei basin (450 km long and 15–20 km wide) for at least 11,500 ^{14}C years, from ca. 24,900 to ca.13,300 BP (or 12,000 calendar years, ca. 28,000–16,000 cal BP). Although big game hunting was one of the main human economic activities, human pressure did not result in mammoth extinction or migration.

There are no *direct* evidences of mammoth hunting by prehistoric people in the Upper Yenisei basin. At the Shestakovo site in southern Western Siberia where mammoth bones are abundant and ^{14}C-dated to ca. 24,400–18,000 BP, Upper Palaeolithic humans may have scavenged subfossil mammoth remains from a nearby natural surface accumulation (so-called 'mammoth cemetery') (Derevianko et al., 2000; Zenin, 2002, pp. 40–41; Zenin et al., 2000a,b). The lack of evidence for extensive mammoth hunting from the Yenisei River basin and from Siberia as a whole argues against the idea that mammoths were an important food resource in the Upper Palaeolithic. There is the single *direct* evidence of mammoth hunting for the whole of Siberia from the Lugovskoe site in central Western Siberia (Pavlov et al., 2002, pp. 171–172). The evidence consists of a cone-shaped hole in a mammoth thoracic vertebra caused by the penetration of a notched point, with pieces of quartzite notches lodged in the hole. In European Russia, there is also the single *direct* evidence of mammoth hunting, a projectile point in a mammoth rib from one of the Kostenki sites (Maschenko, 2002, p. 81). Most probably, the scale of mammoth hunting was very restricted, and people primarily hunted smaller animals, such as deer, bison, horse, and other ungulates. We have no solid evidences to suggest that human hunting pressure had a significant effect on Siberian mammoth populations, and Palaeolithic humans cannot be considered as an important agent in the process of mammoth extinction in Siberia after the Last Glacial Maximum, i.e. from ca. 20,000 to ca. 12,500 BP.

Thus, humans and mammoth populations coexisted in Siberia for a long time. It is important that the dispersal of prehistoric humans in Siberia beginning at ca. 24,000 BP, especially across the northeastern part of Siberia, did not cause an abrupt reduction of mammoth habitat. This began at ca. 12,000 BP throughout northern Asia, both within and beyond the prehistoric ecumene of that time.

8. Reconstruction of mammoth habitat patterns in Siberia at the Pleistocene–Holocene boundary, ca. 10,500–9500 BP

As has been noted before (cf. Sulerzhitsky, 1997; Sher, 1997a,b,c; Kuzmin et al., 2000, 2003; Orlova et al., 2000a), up to ca. 13,000–12,000 BP the mammoth habitat covered almost all of northern Asia. The ^{14}C-dated mammoths for the time interval of ca. 18,000–12,000 BP are known from the eastern Chukchi Peninsula (Uelen, 170°W) up to the Irtysh River (69°E); and from the Kotelny Island and the Taymyr Peninsula in the north (75–76°N) to the southern West Siberian Plain (55°N), southern Eastern Siberia (53°N), and the southern Far East, Primorye and Manchuria (44–47°N) in the south.

Mammoths with ^{14}C dates of less than ca. 12,000 BP were known up to the year 2000 only for the Arctic coast of Siberia, north of 69°N in the lower stream of the Indigirka River (Berelekh locality), on the Severnaya Zemlya archipelago, and on the Taymyr, Gydan, and Yamal Peninsulas. The latest ^{14}C dates of ca. 9900–9700 BP are known for the Taymyr. For the Gydan, they are ca. 10,000 BP and for the Yamal Peninsula and the Indigirka River ca. 10,400 BP (Fig. 6). On Wrangel Island, the latest ^{14}C date for the typical *M. primigenius* is ca. 12,000 BP; the small-sized *M. primigenius vrangeliensis* existed at ca. 7700–3700 BP.

The most detailed studies of the mammoth environment in the Late Glacial have been carried out at two localities, Berelekh (Vereshchagin and Ukraintseva, 1985; Lozhkin, 1998) and Yuribei (Ukraintseva, 1982). At the Berelekh site in arctic Northeastern Siberia, mammoths existed in an environment of tundra with light larch forests in the river valleys. The end of the mammoth bone accumulation at Berelekh (the latest ^{14}C date is ca. 10,400 BP) corresponds to an increase of birch and alder in the pollen spectra, dated to ca. 11,800–10,300 BP. This reflects a change in vegetation from grass and shrub tundra to forest tundra, later with larch trees. The Yuribei mammoth in the northern West Siberian Plain existed at ca. 10,000 BP in the warming environment, with vegetation represented by shrub tundra with larch.

As has been pointed out, up to the year 2000 there are no ^{14}C-dated mammoths with an age of less than ca. 12,000 BP outside of the High Arctic. However, the situation has significantly changed with new ^{14}C dates published in the years 2000–2002 (Sulerzhitsky et al., 2000; Orlova et al., 2000a, 2002; Stuart et al., 2002; Pavlov et al., 2002). The new dates were obtained from central and southern Western Siberia, the Volchya Griva (ca. 11,100 BP) and the Lugovskoe (ca. 12,800–10,200 BP) localities (Fig. 6). It seems that even after ca. 12,000 BP in a few places in Siberia, as well as on the North European Plain (the Puurmani and the Cherepovets localities—see Stuart et al., 2002, p. 1564), some mammoth populations survived until the beginning of the Holocene. Thus, the mammoth habitat dynamics model of the 'retreat to the north after 12,500 BP', created by Sher (1997c) after summarizing data available up to the mid-1990s, should now be corrected. The process of the mammoth habitat "decay" was more complex then it was previously thought, with isolated mammoth populations surviving outside of the Arctic until ca. 10,000 BP.

An important question which needs to be addressed is the place and time of origin of small-sized mammoth on Wrangel Island, *M. primigenius vrangeliensis*. The ^{14}C dating of mammoths is undoubtedly one of the most reliable methods to study their extinction in the Holocene (Martin and Stuart, 1995). Small-sized mammoths are known from Wrangel Island in the Holocene (ca. 7700–3700 BP) (Vartanyan et al., 1993, 1995). However, similar 'small'-sized mammoths are also known in the Late Glacial (ca. 13,700–10,400 BP) in the mainland of Northeastern Siberia (Tikhonov and Vartanyan, 2001; Tikhonov et al., 2003). Sulerzhitsky and Romanenko (1999: 255) suggested that mammoths could migrate to Wrangel Island from the neighbouring island refugia composed of ice-enriched deposits, which were destroyed by thermal abrasion during the Holocene transgression of the Arctic Ocean. The study of ^{14}C chronology of the latest mammoths in the extreme Northeastern Siberian mainland around Wrangel Island may provide new information about the history of the Wrangel mammoth population at the end of the Pleistocene (A.N. Tikhonov, pers. comm. 2002).

The 'normal' size mammoths existed on Wrangel Island until ca. 12,000 BP (LU-2823 date, Table 1). Up to ca. 12,500 BP, Wrangel Island was connected with the mainland of northeastern Siberia (Lozhkin, 2002, p. 7; Lozhkin et al., 2001). This means that mammoth could easily move around until this time. The vegetation of Wrangel Island in the Late Glacial, before ca. 10,000 BP, was tundra (Lozhkin et al., 2001). Other data indicate the occurrence of shrub birch at ca. 12,500–8000 BP (Lozhkin et al., 2001, p. 230). According to S.L. Vartanyan (Lozhkin et al., 2001, p. 231), the climatic amelioration on Wrangel Island occurred at ca. 10,000–9000 BP, with a warmer and likely moister climate than at present (Lozhkin et al., 2001). It is clear now that the Holocene environment of Wrangel Island was definitely not of the 'full-glacial type' where small-sized mammoths could survive after the disappearance of the 'mammoth landscapes' (Lozhkin et al., 2001, p. 232). Thus, palaeoenvironmental data do not add any new clues about the cause of mammoth extinction on Wrangel Island.

9. Conclusion

The data on chronology and environment of the woolly mammoth in Siberia, collected and reviewed here, create the background for a detailed study in the future of mammoth ecology and environment in the Northern Hemisphere. The significant progress in ^{14}C dating of mammoth remains in northern Eurasia, achieved in the 1990s and the early 2000s, allows us to reveal new patterns of mammoth history, such as the complex process of their extinction at the Pleistocene–Holocene boundary, ca. 10,000–9500 BP, with few refugia outside of the Arctic at this time. The process of the emergence and environmental history of the small-sized mammoths from Wrangel Island has so far not been well-studied.

Much more work needs to be done in order to understand the peculiarities of Pleistocene megafaunal existence and extinction, and Siberia is undoubtedly one of the key areas in these studies. Thus, we can expect new and more detailed data about the extinction of mammoth and other large mammals in Siberia, such as wooly rhinoceros, bison, horse, and giant deer, in the next decade or two.

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